ITB Bandung, 28-29 March, 2016

Pre-workshop short-course
Company decision-making for geothermal projects
(GEOCAP Work Package 1.07)

5th ITB International Geothermal Workshop 2016, Bandung

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Cooperating companies & Universities

INAGA

IF Technology

DNVGL

Institute Teknologi Bandung

Delft University of Technology

Department of Geo-Technology

University of Twente

Faculty of ITC

Universitas Gadjah Mada

Universitas Indonesia

University of Utrecht

Faculty of Geosciences – Department of Earth Sciences

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Proposed additional members:

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Funded by

Ministry of Foreign Affairs of the Netherlands

GEOCAP full courses WP1.06-1.07-1.08

Course title/focus	Target Group
1.06 - Government policy-making and decision-making for geothermal projects Energy policy framework: broader perspective of renewable energy market, role of GTE. Understanding GTE policy framework, government take + investment climate, learning + updating. Authority decision-criteria and decision-making: tendering, licensing and permitting, COD, financial closure. Also: subsidies, guarantees, govt. participation. Interaction with company decision-making.	Central govt. policy-makers, Competent Authority licensing and permitting decision-makers. Industry representatives.
1.07 - Company decision-making for geothermal projects Framing the problem. Decision and Risk Analysis: methods, multi-criteria, techno-economic models (physics + discounted cash flow analysis), production forecasting, uncertainty, sensitivity analysis, risk mitigation, value of information, value of flexibility. Decision-gate process, project maturation. Corporate portfolio analysis. Multi-stakeholder analysis.	Corporate decision-makers, company engineering / corporate planning staff, company economists. Government representatives
1.08 - Environmental aspects of geothermal projects Sustainable GTE planning and decision-making in Indonesia: logic, efficiency, effectiveness, transparency and stakeholder involvement.	Government, Industries, Academicians and local stakeholders.

Course 1.07
Company decision-making for geothermal projects

IIGW pre-workshop short-course

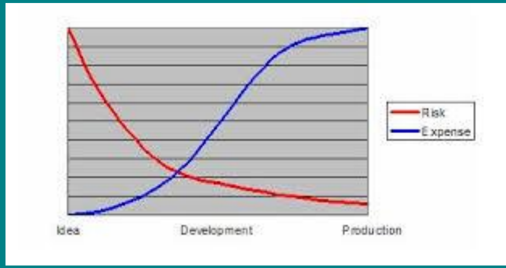
- Just an '*appetizer*' for the full 1.07 course later this year
  - Main pertinent topics of Investment decision-making will be reviewed
- Full course will take 5 days
- Full course will be updated and repeated in 2017
- All participants are recommended to enlist for the full course
  - *Note: thinking in terms of forecasts, uncertainties, options, robustness etc. generally puts people out of their comfort zone: it takes effort and time to grasp the concepts!*
  - *Even the full course is far too short, it will only give you a flavour. This short-course will merely give you an inkling of a flavour!*
- GEOCAP offers the possibility to participate in R&D on decision-support tools

Decision-making processes:

Decision Gate process

Decision Analysis process

"Nothing is more difficult, and therefore more precious, than to be able to decide" - Napoleon Bonaparte



Why is investing in subsurface unlike any other industrial activity?

- Technology / production forecasting uncertainty
  - Revenue uncertainty due to *technical* uncertainty (data scarcity)
- Economics / commercial complexity
  - Capex / opex uncertainty
- Governance
  - Legal / fiscal / regulatory complexity
- People management
- Public acceptance (HSE&SR)
- Integration skills
  - Learning from experience

***Summarizing*: committing high capex when productivity of asset is still very uncertain**
→

- **High technical risk +**
- **High non-technical risk**
- **This must be balanced by high expected *Return on Investment***

Decision analysis (DA)

ref. Wikipedia

- Decision analysis (DA) is the discipline comprising the philosophy, theory, methodology, and professional practice necessary to address important decisions in a *formal* manner.

- DA includes many *procedures, methods, and tools*
  - for identifying, clearly representing, and formally assessing important aspects of a decision,
  - for prescribing a recommended course of action by applying the maximum expected utility action axiom to a well-formed representation of the decision, and
  - for translating the formal representation of a decision and its corresponding recommendation into insight for the decision-maker and other stakeholders.

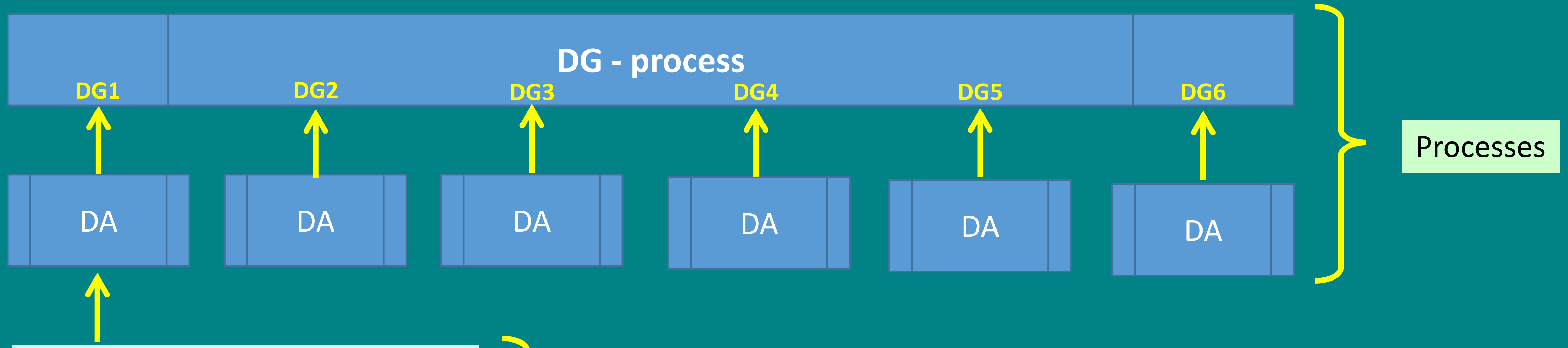
What techniques and processes will be discussed? Some essentials:

- **Decision Gate process** – project maturation from brainwave to bankability to FID
- **DA process** – Decision Analysis, to be updated at various 'Decision Gates'
- **Framing** – Part of DRA process: defining uncertainties, decision alternatives, models, decision criteria
- **DTA** – Decision Tree Analysis: setting up a logical structure for Decisions and Scenarios
- **T2B** – Technical-to-Business: modelling technique to couple physics/technical/economics (and HSE)
- **Basic Statistics** – understanding how to model uncertainties, 'Frequentists' vs. 'Bayesians', preventing bias / psychology
- **MC** – Monte Carlo, probabilistic sampling technique for modelling uncertainties, incl. correlations
- **SA** – Sensitivity Analysis: understanding main high-impact uncertainties + what to do about it
- **Robustness** – definition of robustness: how to use this when recommending a decision?
- **CAPM & WACC** – Capital Asset Pricing Model & Weighted Average Cost of Capital: how to use in DCF?
- **DCF** – Discounted Cash Flow analysis: understanding the underlying assumptions of DCF analysis
- **VoI** – Value of Information: understanding when to propose new data acquisition
- **VoF** - Value of Flexibility: understanding when to propose flexibility-options in an engineering design
- **MPT** – Modern Portfolio Theory: better understanding the nature of risk and how the portfolio of projects determines how to assess individual project risk.
- **MSA** – Multi-Stakeholder Analysis: understanding how to make a Multi-Stakeholder project fly
- **DQ** – Decision Quality: a way to measure and monitor the quality of the decision-making process

Many other methods, e.g.

- **Real Options Valuation**
- **Complexity theory**
- **Agent-Based Modeling**
- **System Dynamics**
- **Bifurcation theory**
- **Resilience testing**
- **Etc. etc.**

Company decision-support processes & methods



- **Framing, DTA**
- **DCF, CAPM+WACC**
- **T2B**
- **Basic stats, MC**
- **SA, VOI, VOF, Robustness, MSA**
- **MPT**
- **DQ**

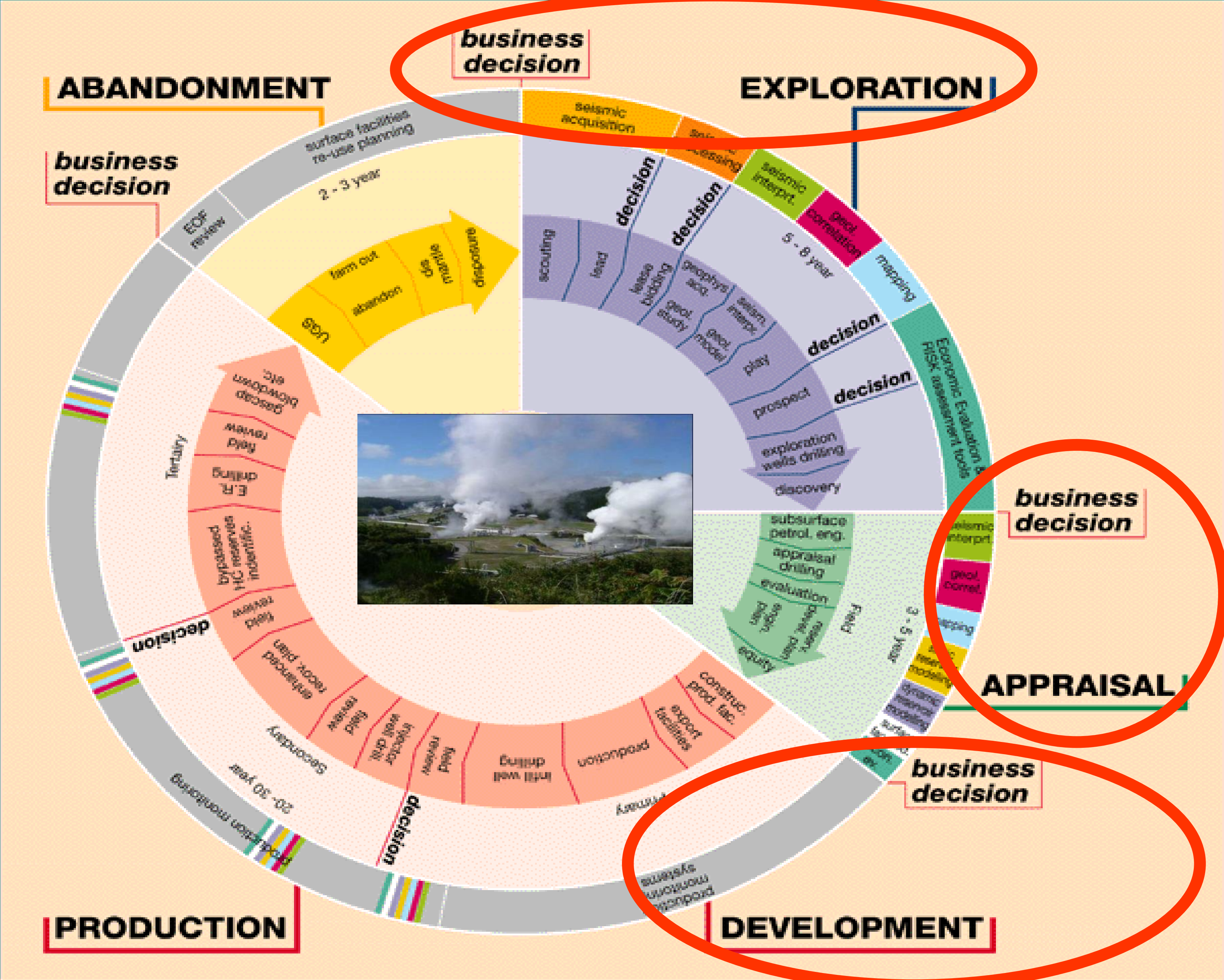
Methods, techniques

The *DG-process* is repeated *n* times over an asset's different life-cycle *phases*.

Geothermal Asset Lifecycle

- 5 main phases
  - + 6th: Monitoring
- Many major decisions:
  - Inter-phase
- And minor decisions:
  - Intra-phase

GT Asset is depletable in economic terms , i.e. non-renewable.
ABD decision based on increasing Opex vs. declining revenues (30 yrs?)



GT asset life-cycle phases

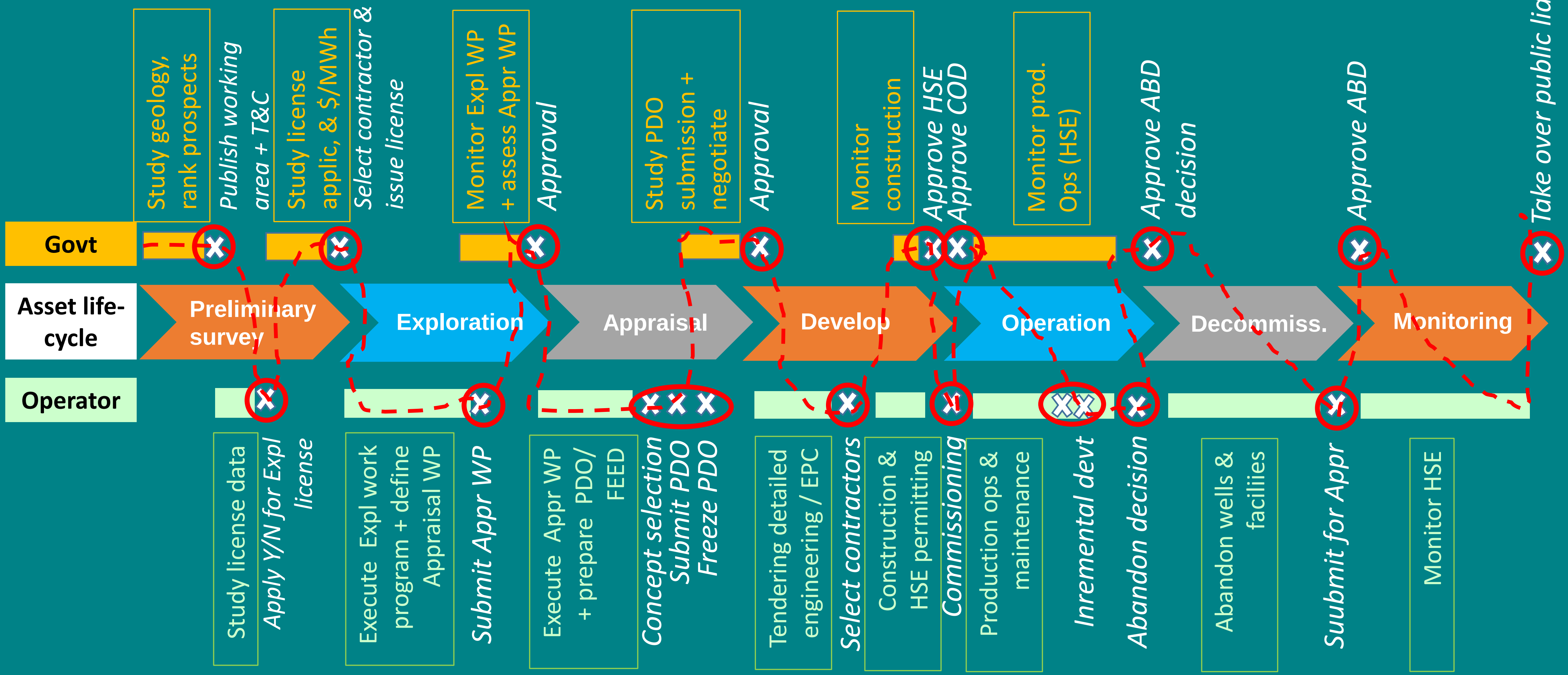
'Preliminary survey' (pre-phase): *Govt site selection + inviting exploration bids*, leading to

- Operator DG '***Exploration license application***', followed by *Operator/Govt negotiations* + if successful:
- Govt DG '***Exploration license granting***'

1. Exploration, if promising leading to
   - Operator DG '***Appraisal work programme***' (or directly to DG '*Conceptual engineering*').
2. Appraisal, leading to
   - Operator DG '***Conceptual engineering***' (or FEED: Front-End Engineering & Design),
   - Operator DG '***Concept selection***' and
   - Operator DG '***Production license application***' + Govt DG '***PDO sanction***'
3. Development
   a) *EPC activity* (Detailed Engineering – Procurement – Contracting)
   - Leading to Operator DG '***FID***' (***Final Investment Decision***)

   b) *Construction activity* (leading to DG '***Commissioning***' and '***COD***')
4. Operation (production operations & maintenance / exploitation)
   - Direct or indirect utilization (condition of license)
   - Including Operator DG's for '***Incremental development(s)***'
5. Decommissioning (joint Operator and Govt decision)
   - Dismantling surface installations + abandoning wells (+ prepare for mandatory monitoring)

Asset life-cycle Decisions: Govt. vs. Operator



New Geothermal Law Indonesia

- Target
    - Increase GT capacity from 1.4 GW (2015, from ca 300 locations) to 3.2 GW (2020)
    - And in 2025, capacity should be 5.0/6.5/9.5 GW (unofficial estimates)
    - New GT law should stimulate this
- Some characteristics
    - GT is no longer a mining activity, i.e. no royalty on depletable resource, environmentally less constrained
    - 2 types of licenses: indirect and direct utilization (indirect : conversion to e)
    - If indirect license, PLN must construct a transmission line
    - PLN must prepare a PPA – Power Purchase Agreement
    - Feed-in tariff is geographically determined
    - Various barriers have been removed (ref. previous GT law): GT in forests, bureaucracy
    - Tendering process (license bidding) still to be formalized
    - Authorities assess the financial capabilities and work programme of the bidder
    - GFF = Geothermal Fund Facility to promote GT exploration
- Some concerns on new GT law
    - There are potential conflicts with other energy laws in Indonesia:
        - Overlapping permits with other activities (land conflicts, access roads)
    - In case of bank loans, operators have difficulty in providing adequate collateral
    - Public acceptance (nimby) is often a problem

Government GT decision-making

Action / Milestone Decision by Government	Required information / knowledge by Govt
1. Prioritize open GT-acreage	Regional information on geology, and experience with nearby GT-fields
2. Publish license bidding round	Terms and conditions that will apply to new GT field operators, description of geology and market.
3. Evaluate Exploration license bids by operators	Operator Exploration Work Program, including conceptual PDO (Plan for Development and Operation) and proposed tariff/MWh
4. Prioritize Exploration license bids by operators	Govt policy on which KPIs to consider and how. Understanding of how these KPIs have been established by the operator and how to interpret them. Understanding the risks in the forecast Govt Take.
5. Enter further negotiations & select Operator for Exploration work program	Establish details of Exploration license agreement
6. Evaluate PDO submission + grant GT Production license	In case of Exploration discovery, assess PDO submission + impact of detailed T&C on Govt Take and on govt GT-policy
7. Monitor operator's execution of field devt, establish COD	Data & info from field as supplied by operator, fiscalized volumes as obtained from other authorities (tax, regulator, etc.)
8. Influence operator's updating of PDO as new info is being revealed in time. Eventually: Abd decision	Info & know-how on operations, on cash-flows and on impact on general GT policy. For Abandonment decision, Govt needs to understand remaining potential of field.

Govt KPIs for assessing *exploration* license applications

- Information / knowledge obtained as a result of the Exploration Work Program submitted, to the effect it may help further regional exploration
- Competence / track record of company in terms of exploration successes
- Financial capability of company (competence/track record)
- HSE&SR impact analysis of Exploration Work Program
- HSE&SR competence / track record of company

Govt KPIs for assessing *production* license applications (some examples)

- MW capacity installed + timing
- MWh tariff sold to PLN
- Expected GWh to be produced per year + uncertainty
- Track record and financial capability of Operator
- Yearly expected cash flow from Govt Take (corporate tax mainly) + uncertainty around this expectation
  - Incl. risk of losing tax income from other assets (if not ring-fenced)!
- HSE&SR impact analysis of PDO

Learning

- Information / knowledge obtained as a result of the project, which may help future projects meeting the companies' hurdle rates
- Information / knowledge obtained as a result of the project, which may help the government to negotiate better T&C of new projects

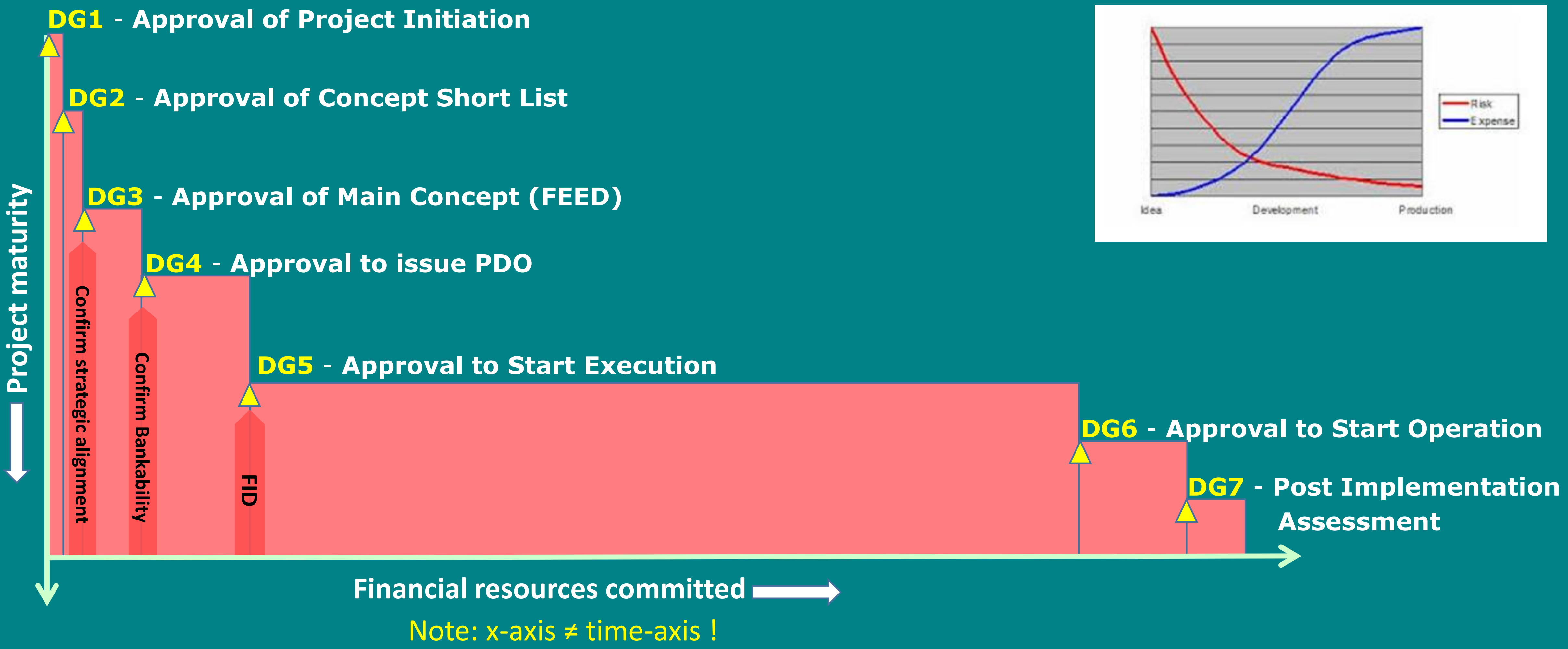
Company Decision Gate process (Statoil)

- Project maturation from brainwave to bankability to FID
  - **DG1 - Approval of Project Initiation**
    - Validate basis to pursue the business opportunity, initiate the project
  - **DG2 - Approval of Concept Short List**
    - To confirm that *resolution of uncertainties* supports continuation of project definition and move to Concept selection. Has the project been effectively framed and is there a sufficient knowledge to start the process of **selecting** the concept and defining the plan?
  - **DG3 - Approval of Main Concept**
    - To confirm approval of the Concept Selection
  - **DG4 - Approval to issue PDO (Plan for Development and Operation)**
    - Project considered sound & ready to execute, prior to & conditional on PDO approval
  - **DG5 - Approval to Start Execution**
    - To confirm that the conditions as at DG4 are still valid
  - **DG6 - Approval to Start Operation**
    - To confirm ready to start operation and hand over of Operator ship
  - **DG7 - Post Implementation Assessment**
    - To assess to what degree the objectives of the development project have been fulfilled
    - To assess whether Operations are being undertaken in accordance with requirements
    - To provide experience feedback for future projects

Confirm Bankability

FID – Final Investment Decision

Decision Gates vs. financial commitment



Bankability

- Commercial banks vs. development banks
  - Less control by bank / higher costs vs. More control / lower costs
- Corporate financing (balance sheet): equity vs. loan
- Project financing (collateral = project)
- World Bank criteria:”due diligence”. This includes many steps, e.g.
  - Approved project implementation plan, responsibilities of parent company with respect to subsidiary company receiving and managing the loan, interest rate + debt repayment schedule, company solvency, tendering process, accountancy standards + financial monitoring plan, HSSE&SR safeguards, dispute settlement, etc.
  - Consistency with WB’s Country Partnership Strategy and overall WB objectives
  - And many other!

Decision Analysis process (1)

- DA process is to be updated at various 'Decision Gates'

1. Frame the problem

- Agree dec. crit.
  - ✓ opt. criteria
  - ✓ opt. constr.
- Risk register
- Agree decisions
  - ✓ static
  - ✓ dynamic
  - ✓ real options
  - ✓ data acq.
- Agree scenarios
- Construct tree
- Prune tree
- Agree tree

2. Set-up quantitative models

- Agree models
- Populate model
- Agree stoch. parameter pdf's & scenario prob.
- Agree / est. correlations
  - ✓regular
  - ✓copulas
- Agree KPIs
- Agree risk def.
- Agree assumptions

3. Generate range of outcomes

- Set MC run parameters
  - ✓ #MC-samples
  - ✓ Sampling type (regular, LHS, …)
- Pdf's of KPIs
- Quantify risks
- Assess impact on portfolio
- Establish utility function, risk tolerance

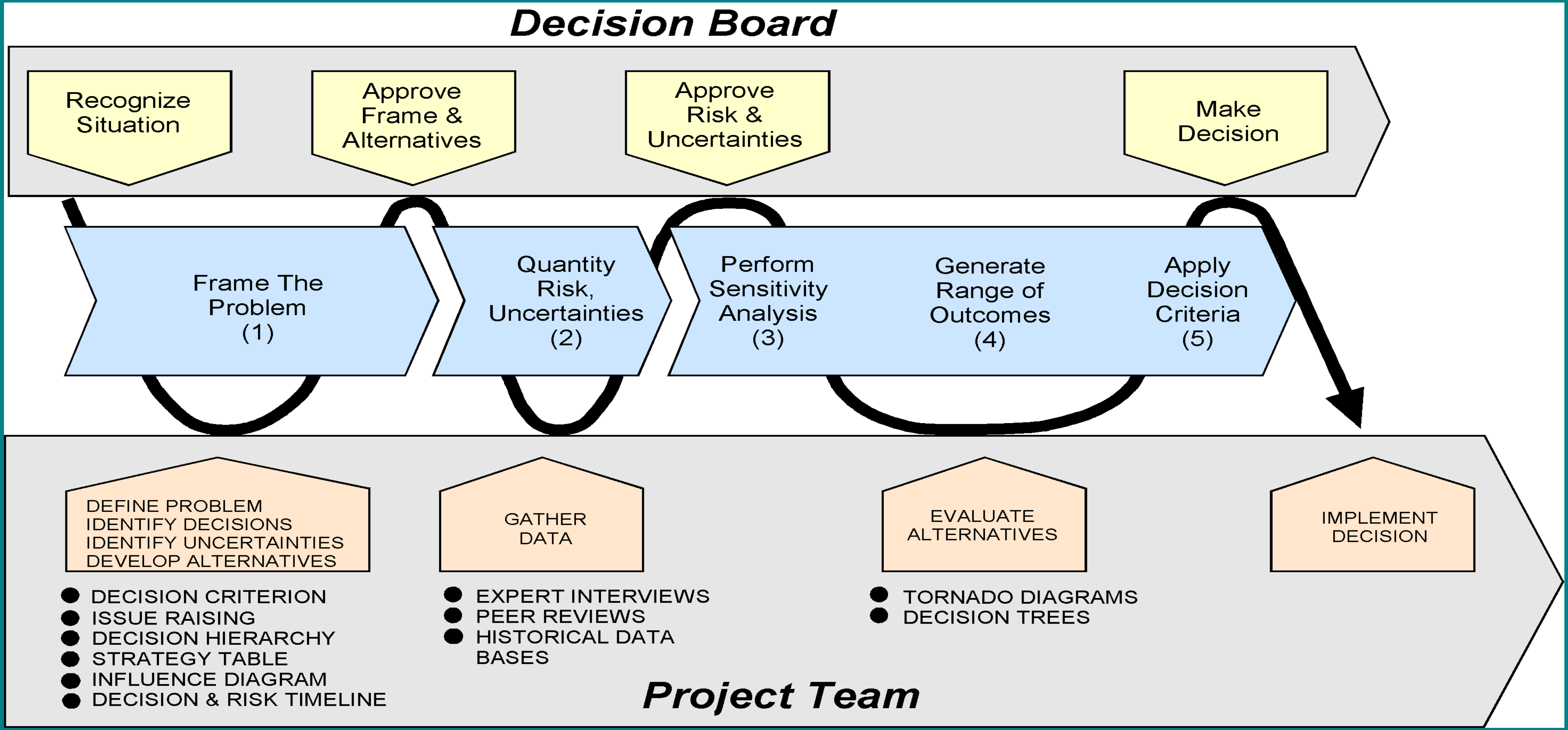
4. Perform Sensitivity Analysis

- Tornado etc.
- Fine-tune decision alternatives.
- Test robustness of decision:
  - ✓ model input
  - ✓ process par
  - ✓ utility function
  - ✓ dec. sequence
- VoI, VoF, ROV
- Define new options from SA

5. Apply Decision Criteria

- Describe process
- Propose opt. solution + impact on portfolio
- Report
- Decide
- Execute
- Monitor
- Update model

The DA Process (2)



Important: consistently and clearly distinguish (terminology)

- *Value drivers or risk factors*
  - Uncertain *model input variables* that may have a material impact on model output KPIs (initially qualitative estimate of sensitivity)
- *Optimization criteria*
  - KPIs ("*Key Performance Indicator*", i.e. uncertain *model output data*, e.g. NPV, next year's average daily production, etc. They can be computed probabilistically using e.g. Monte Carlo sampling of the model input variables + processing T2B model.
- *Boundary conditions or constraints*
  - Internal/external conditions that define frame within which to optimize KPIs
- *Decision alternatives* – you control this, these are your optimization controls
- *Scenarios* - you do not control this; scenarios are *uncertain* and can be described as a consistent set of *uncertain model input variables (scalars* and/or *exogenous time-series), underpinned by a "story-line"*

Threat to understanding each other!

- Be explicit and precise
- Agree on and use a clear **terminology** for risk, scenario, decision, driver, risk factor, hurdle rate, constraint, assumption, etc.

Framing the Problem

- Part of DRA process: defining uncertainties, decision alternatives, models, decision criteria
  - Agree decision criteria:
    - optimization criteria (e.g. NPV, or EMV)
    - optimization constraints (e.g. IRR > x, and/or PoT > *t* years, etc.)
  - Risk register
  - Agree decisions:
    - static decisions
    - dynamic / conditional decisions
    - data acquisition options
  - Agree scenarios, assumptions:
    - E.g. MWh price, inflation, tax %, discount rates, labour cost, etc.
  - Construct tree
    - Prune tree
    - Agree tree

Risk matrix: *per main decision alternative*, make qualitative inventory of expected impact of risk factor on most pertinent KPIs

Uncertain Risk factor ↓	KPI →	Early prod.	Max. exposure	NPV	IRR	ΔUR
Prod. start-up						
Commercial Complexity						
HSE-costs						
Capex-facilities						
Drillex						

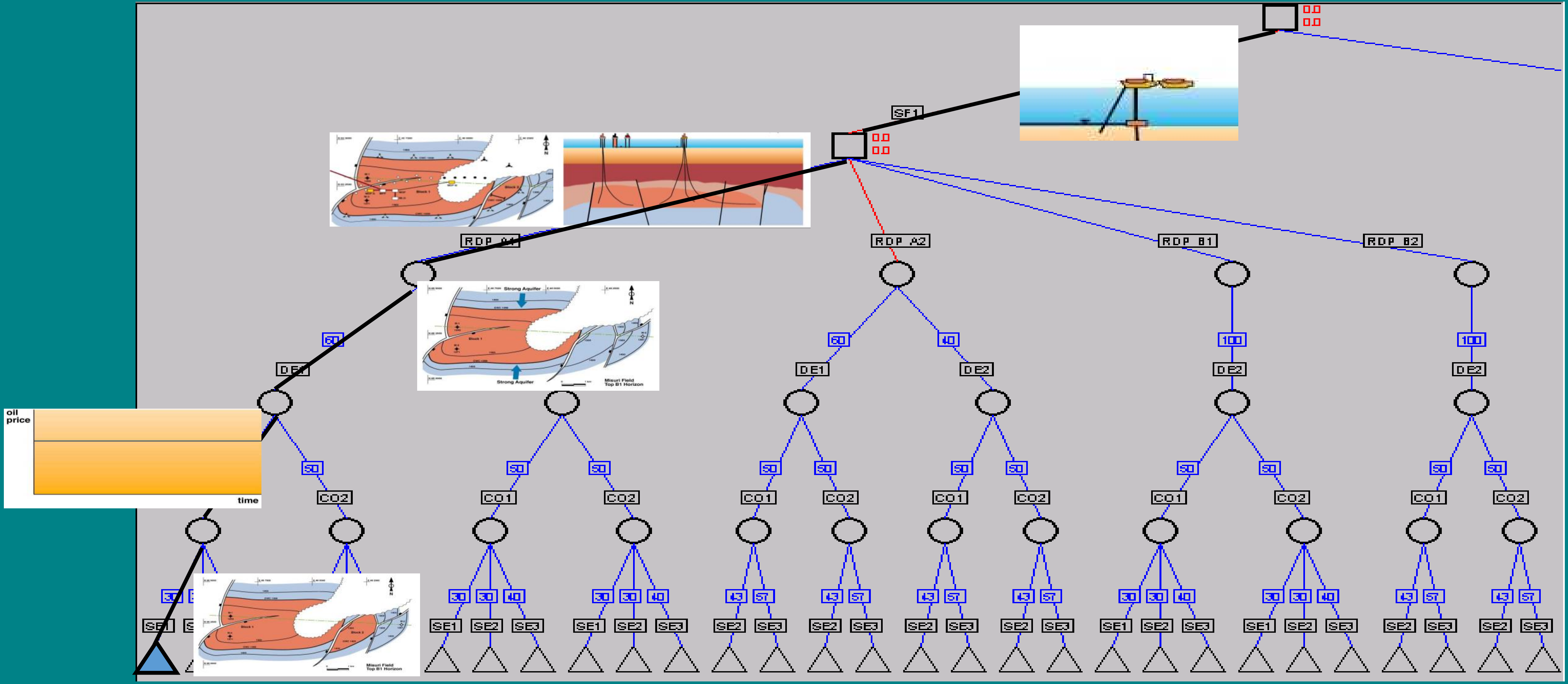
Short term

Life cycle

Long term

- Initially only qualitative, later quantitative. But this allows to dispose early of certain alternatives and prevents further quantification.
- Adverse value of (model input variable) may have a …. (pos/neg) impact on KPI
  - Use qualitative symbols such as ---, --, -, 0, +, ++, +++
  - Ensure mutual consistency of all scores

Framing helps setting up decision tree



DTA- Decision Tree Analysis

- Constructing tree is part of Framing (= part of DRA)
- Setting up a logical structure for Decisions & Scenarios
- A decision tree is a representation of *discrete* decision options (choices) and *discrete* scenarios (non-controllable uncertainties). It shows the (sequential) logic between decision nodes and chance nodes, and allows alternative courses of action to be compared, and preferred courses of action to be analysed.
  - Note: *continuous uncertainties* are not explicit in the decision/scenario tree, but they *can be implicit* in the underlying (T2B) models.
- Caveat: experience shows that Framing and Constructing a decision tree can be *painstaking*.
  - Also, one's understanding of whether or not to model discrete *and/or* continuous uncertainties is typically poor.

Decision node
(with risk&opp. factors)

Dead-end node
(ltd. calc. of FM)

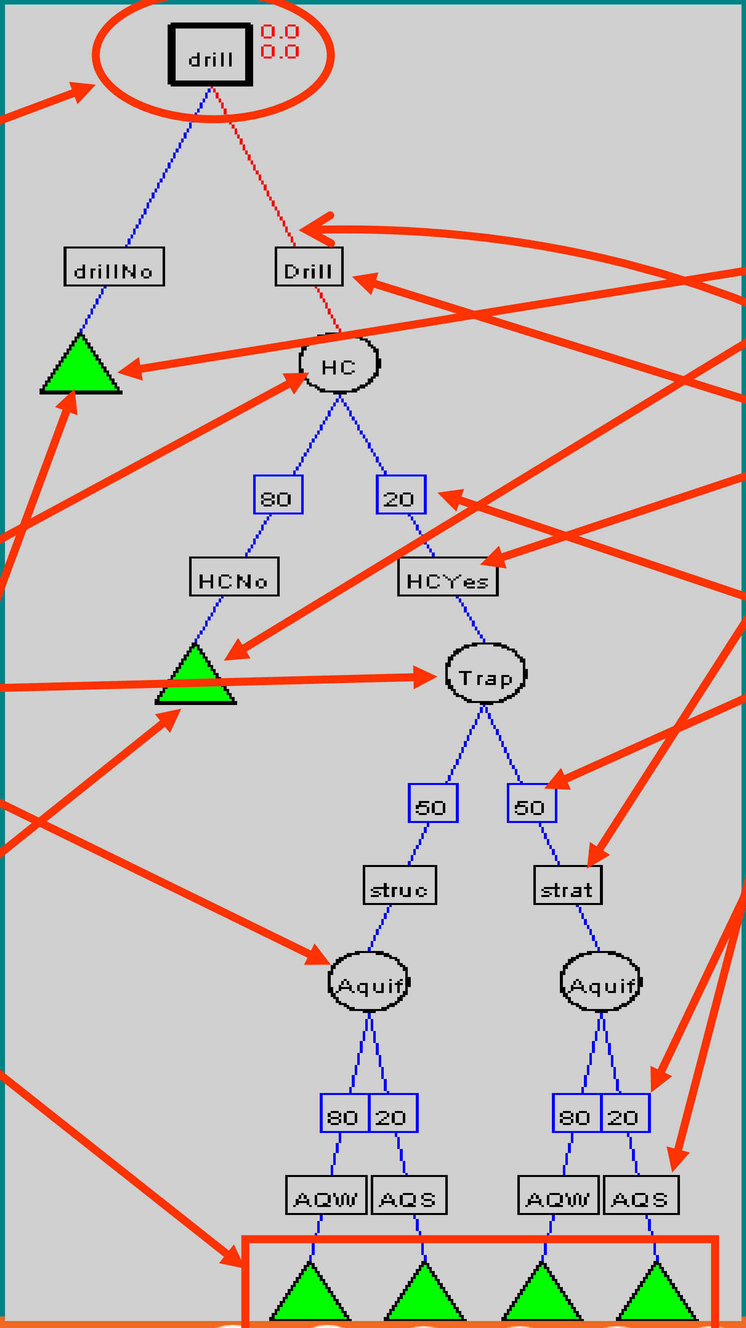
Scenario / decision
name

Scenario chance

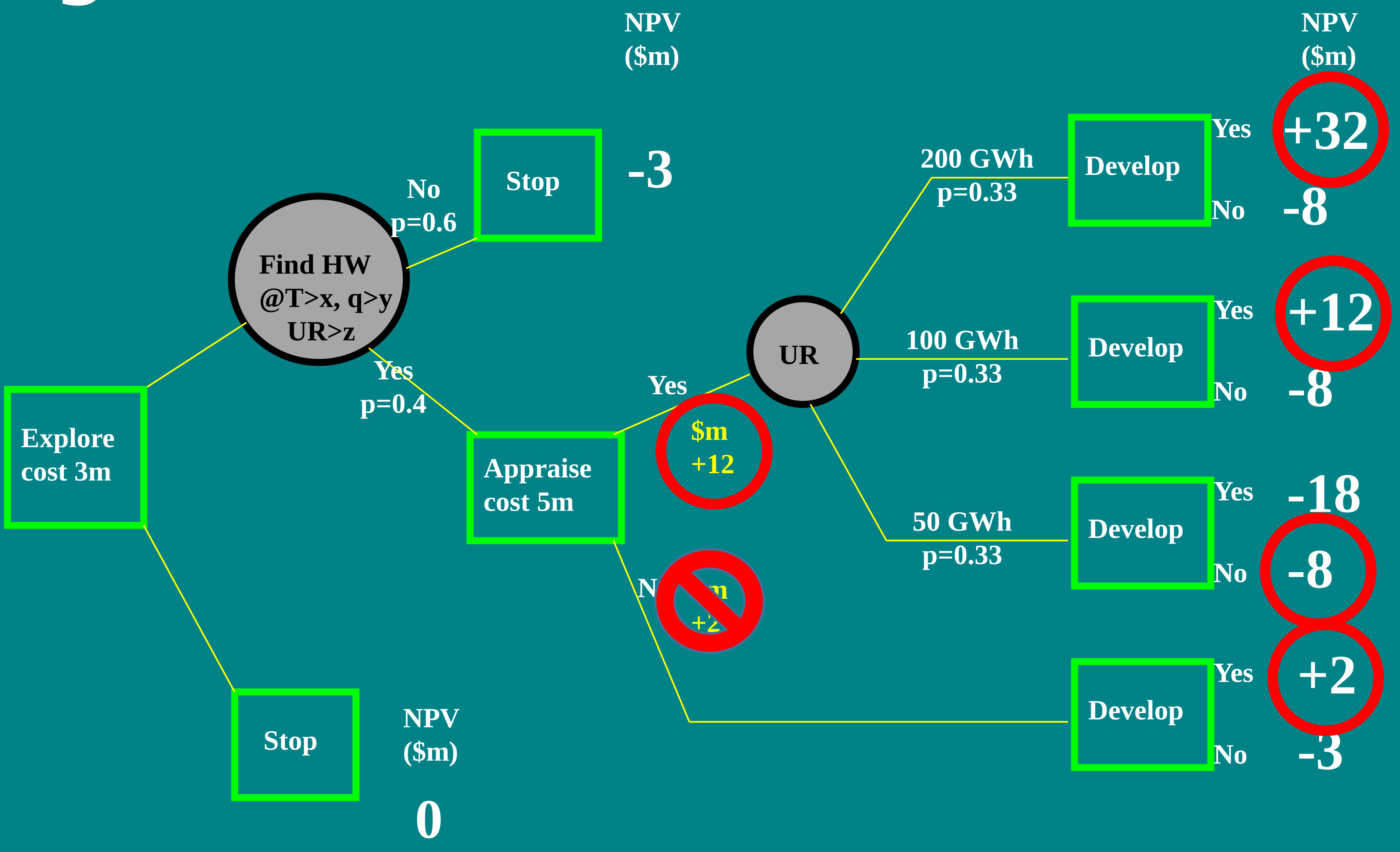
Chance node
(can be conditional)

Optimal decision
(branch coloured red)

End node (leaf)
here calculations in
Fast Models are done



Establish value of GT exploration license through DTA



Solution:

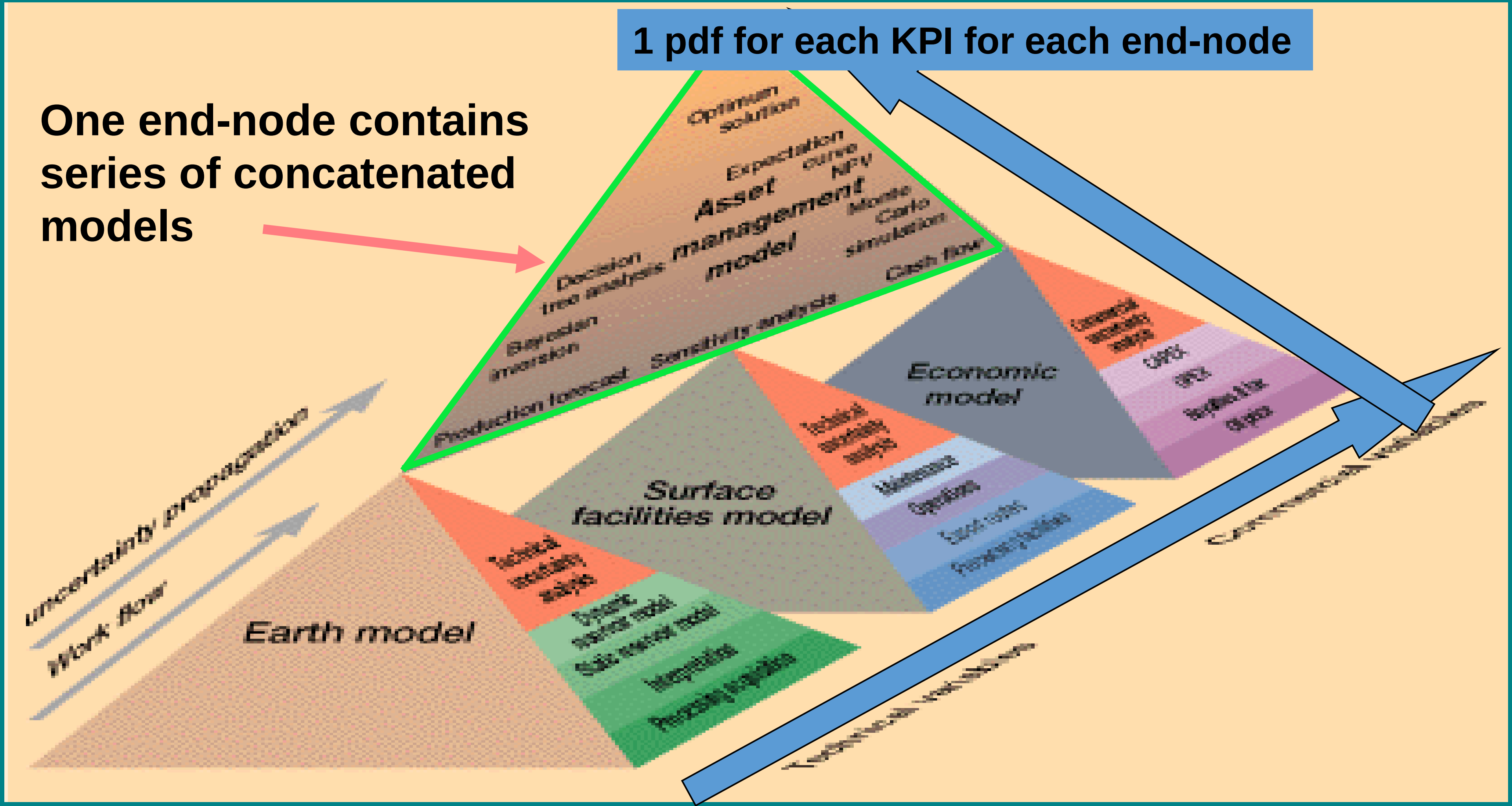
EMV=
0.4*(12)
+0.6*(-3)=
$ 3.0 million

T2B – Technical-to-Business modelling

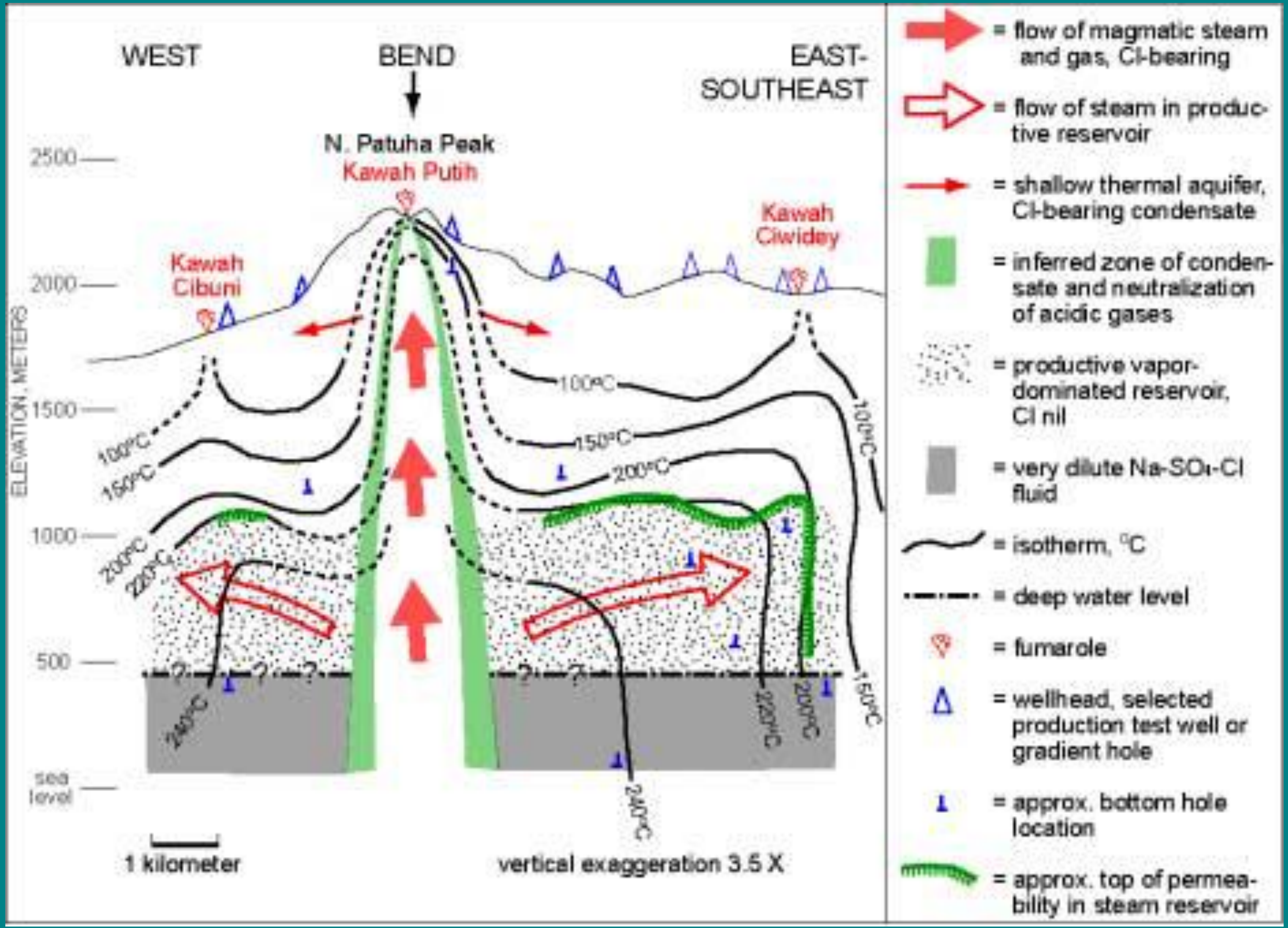
- Modelling technique to couple physics & technical with economics (and HSE)
- See XL model example:
  - Volumetrics: HIIP = Heat-Initially-In-Place
  - Establish thermal conversion efficiency
  - Well capacity from well inflow equation
  - Horsepower required for vertical lift
  - Capex and opex
  - DCF, include price volatility vs. time
  - Monte Carlo, including stochastic correlations

Go to XL worksheet

Concatenated models in each end-node



Patuha case study

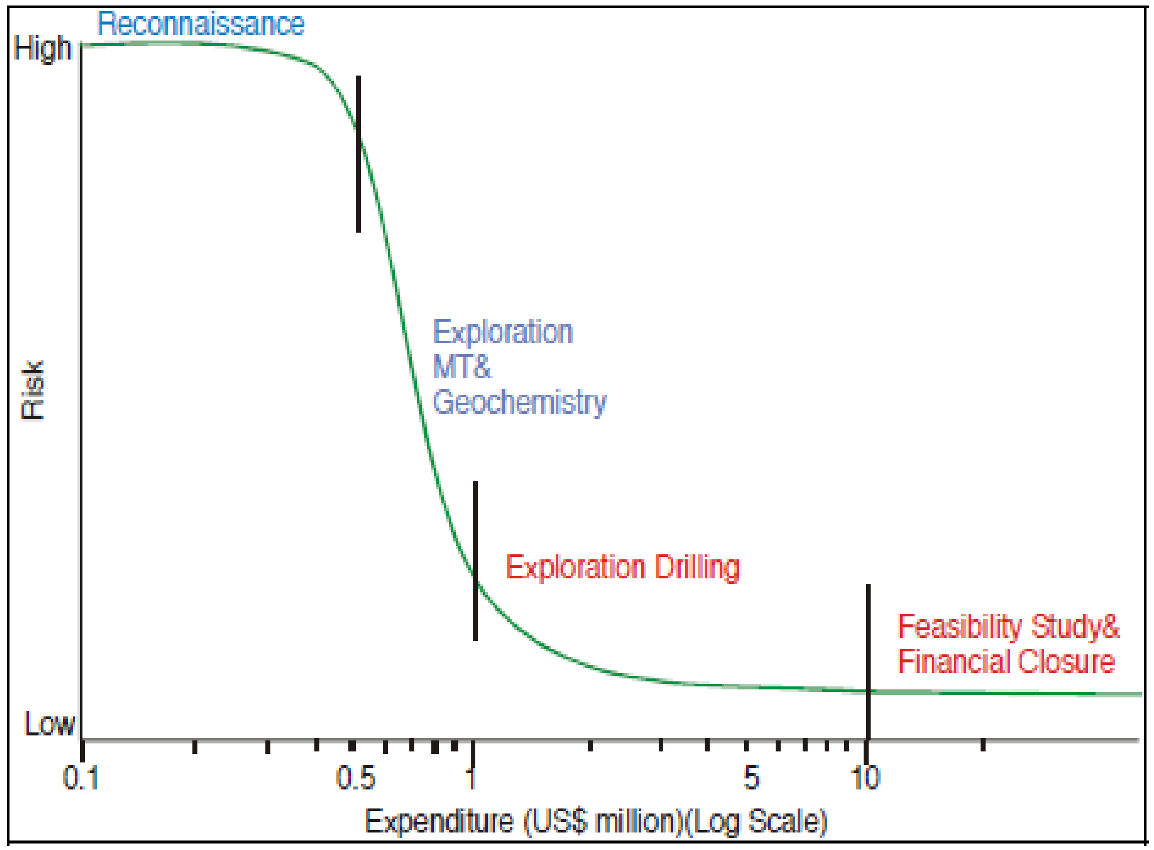


- Friday excursion
- Exploration, development and production history
- Focus on data acquisition and decision-making
- Risks, bankability, etc.

Patuha case study – data acquisition

- Initial temperature 3D-mapping: regional geology, local surface survey (fumaroles etc.), geochemical soil-fluid-gas samples, magnetotelluric-resisitivity-gravity surveys (PT, 1983 – 1989)
- Initial exploratory well drilling (PT): to obtain T-data
- Follow-up surveys (gravity, resistivity), 17 deep T-gradient holes, 13 full production test wells: 9/13 were productive = ca. 72 MWe (PPL, 1994-1998)
- Development suspended 1998 due to dispute with Govt
- OPIC and then Govt takes over ownership 2001 to handover to JV (PT + PLN)

Patuha case, some conclusions



- For bankability / FID, risk must be < tolerance
- Lessons Patuha: data acq and field development 1) take long time; 2) very capital intensive; 3) very uncertain with high technical and political / commercial risk.
- “Low” on y-axis is relative. Risk at FID is still high!

Patuha case, development + capex

- 2003: Geodipa proposed to develop up to 3 X 60 MWe of capacity at Patuha during the period 2003-2006, with a total new investment target requirement of US$250 million.

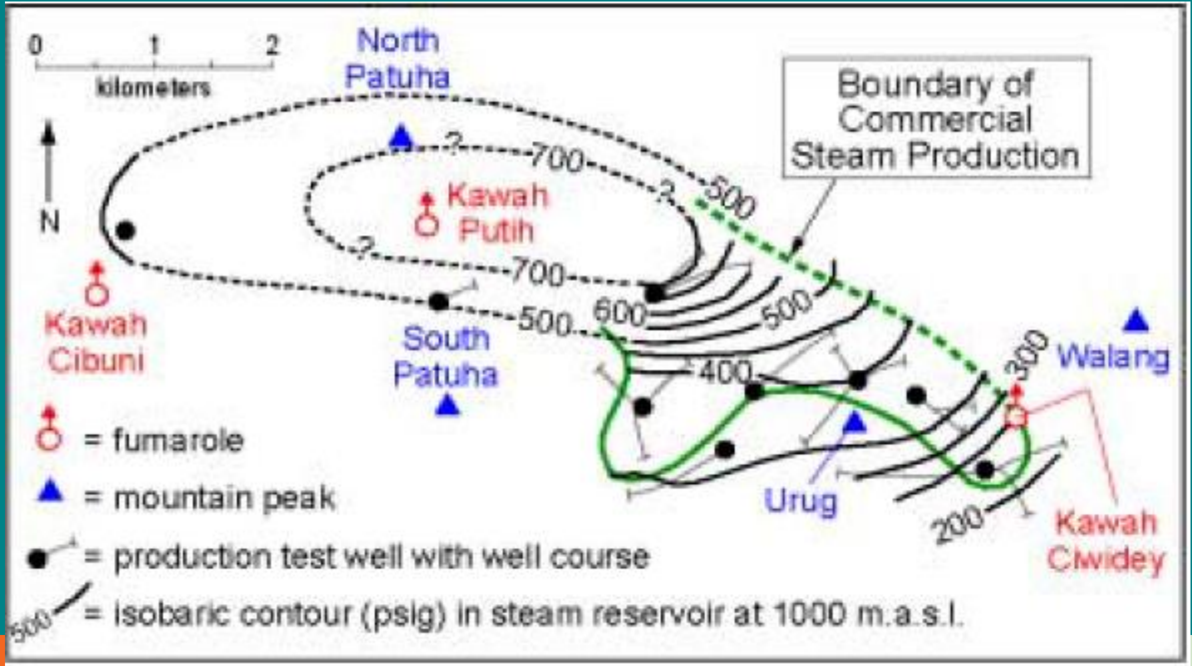
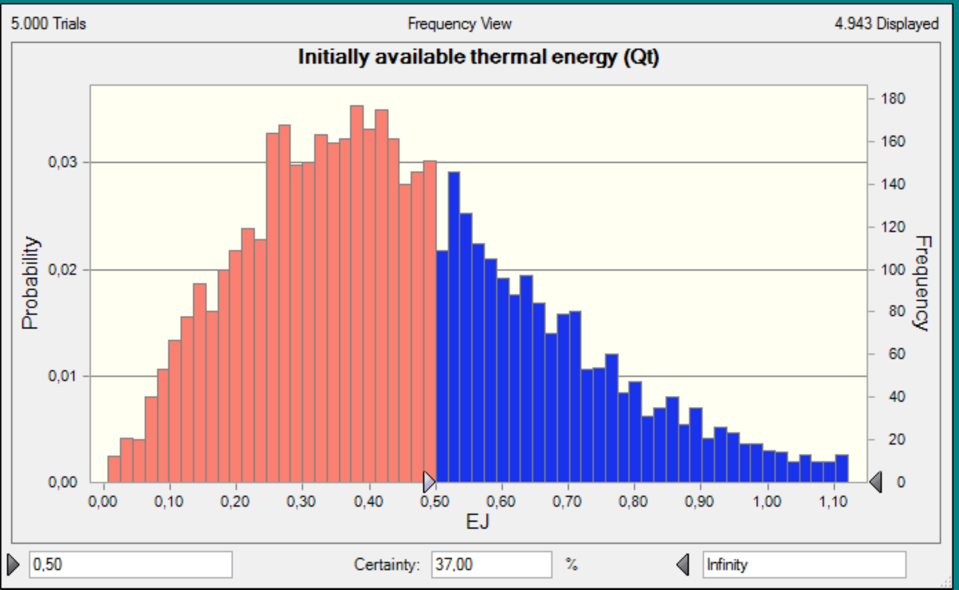
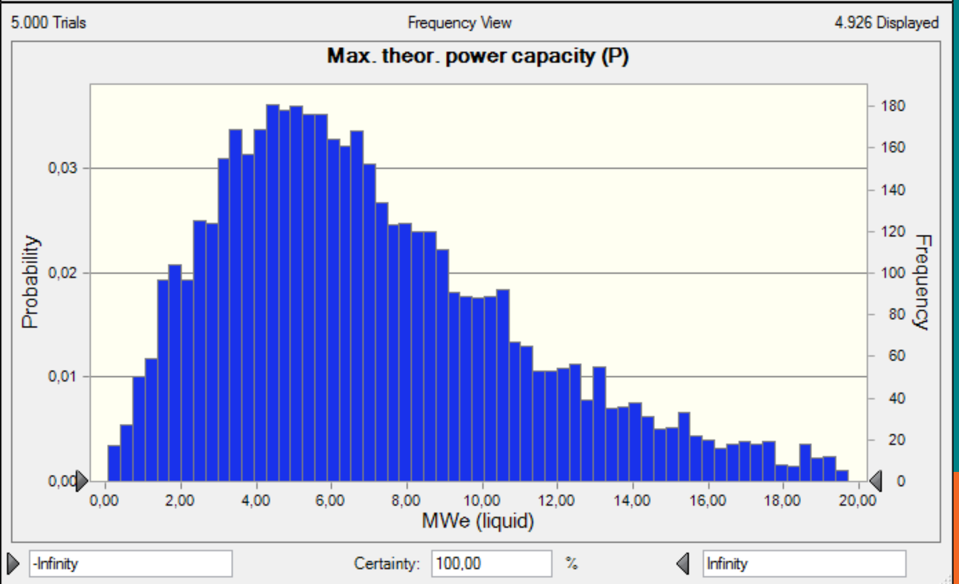
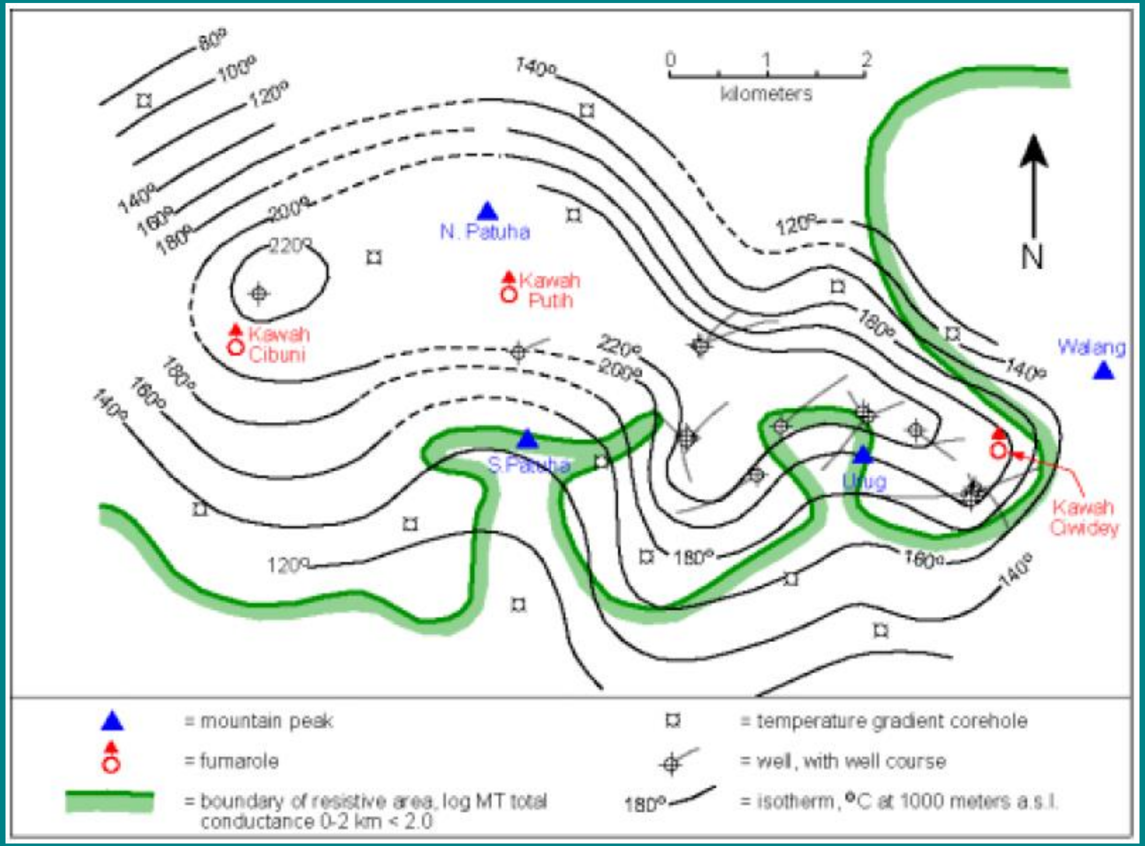


Figure 6. Map of pressures in steam zone and boundary of productive reservoir

Patuha volumetric risk analysis







Ref Layman: Patuha Map of isotherms at 1,000 meters elevation and resistive area boundary

COMPUTER PROGRAMME FOR GEOTHERMAL RESOURCE ASSESSMENT AND RISK EVALUATION USING MONTE CARLO SIMULATION

Ref. Zosimo F. Sarmiento and Benedikt Steingrímsson, Paper UNU-GTP-SC-04-13,
presented at Short Course on Geothermal Development in Central America – Resource Assessment and Environmental Management, organized by UNU-GTP and LaGeo, in San Salvador, El Salvador, 25 November – 1 December, 2007.

Case: Liquid-dominated geothermal reservoir						
GT field name		Patuha				
Liquid phase volume	***Unit***					
Area (A)	*km2*	10				
Thickness (h)	*m*	700				
Rock density (ρr)	*kg/m3*	3000				
Porosity (Φ)	*-*	0,1				
Recovery factor (Rf)	*-*	0,25	See Figure 2 below			
Rock specific heat (Cr)	*kJ / kg. °C*	0,85				
Temperature (Ti)	*°C*	200				
Fluid density (ρw)	*kg/m3*	856,84	See Worksheet 'Water'			
Conversion efficiency (Ce)	*-*	0,142	0,0828	0,092	0,1012	See Figure 3 below
Fluid specific heat (Cw)	*kJ / kg. °C*	4,51	See Worksheet 'Water'			
GT-plant life (t)	*years*	50				
Load factor of plant (Pf)	*-*	0,95				
Rejection temperature (Tc)	*°C*	180				
Initially available thermal energy (Qt)	*EJ (E+15 kJ)*	0,38				
Max. theor. power capacity (P)	*MWe (liquid)*	8,91				

Legend:

(green)	CB distribution of input variable
(light yellow)	Single value input variable
(light orange)	Derived value from other input
(cyan)	CB output value used for histogram

This should be a function of the water properties table in Worksheet 'Water'!

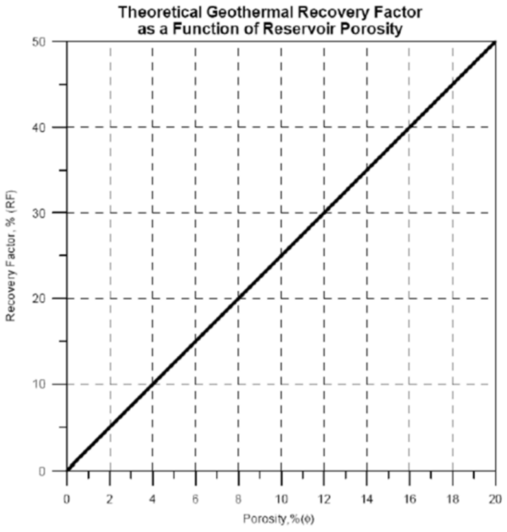


FIGURE 2: Correlation between recovery factor and porosity
(After Muffler, 1978)
RF = 2,5 * Por

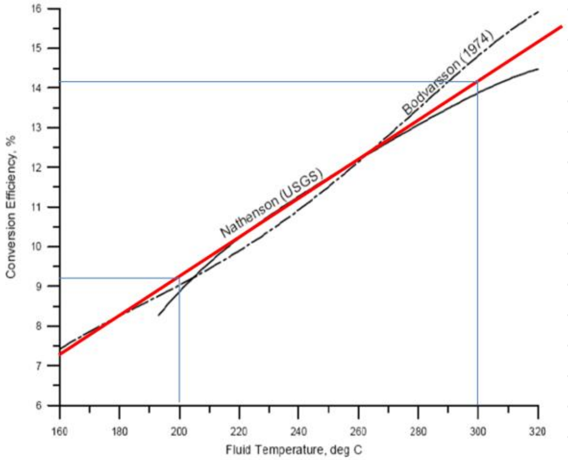


FIGURE 3: Correlation between thermal conversion efficiency and reservoir temperatures (From Nathenson, 1975 and Bodvarsson, 1974).

Approximating this graph by a linear function:

Efficiency	0,092				
x2	300	°C	y2	14,2	%
x1	200	°C	y1	9,2	%

From Sarmiento et al. Paper:

$$Q_T = Q_r + Q_s + Q_w \qquad \textit{Equation (4)}$$

, *where:*

$$Q_r = A \cdot h \cdot [\rho_r \cdot C_r \cdot (1 - \emptyset) \cdot (T_i - T_f)] \qquad \textit{Equation (2)}$$

$$Q_s = A \cdot h \cdot [\rho_{si} \cdot \emptyset \cdot (1 - S_w) \cdot (H_{si} - H_{li})] \qquad \textit{Equation (5)}$$

$$Q_w = A \cdot h \cdot [\rho_{li} \cdot \emptyset \cdot S_w \cdot (H_{li} - H_{li})] \qquad \textit{Equation (6)}$$

, and the following parameters as follows:

Q_T=total thermal energy, kJ/
Q_r= heat in rock, kJ/
Q_s= heat in steam, kJ/
Q_w = heat in water, kJ/
A= area of the reservoir, m^2
h= average thickness of the reservoir, m
C_r – specific heat of rock at reservoir condition, kJ/kgK
C_l – specific heat of liquid at reservoir condition, kJ/kgK
C_s specific heat of steam at reservoir condition, kJ/kgK

Ø= porosity

Ti – average temperature of the reservoir, °C
Tc= final or abandonment temperature, °C
S_w = water saturation
ρ_{si} = steam density, kg/m^3
ρ_w = water initial density, kg/m^3
H_{li}= initial water enthalpy, kJ.kg
H_{li} = final water enthalpy, kJ/kg

3. POWER PLANT SIZING

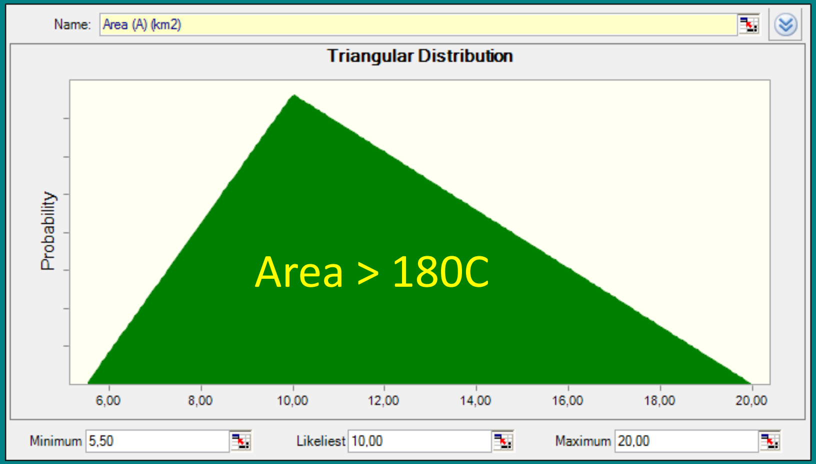
The above calculations only provide for the total thermal energy in place in the reservoir. To size the power plant that could be supported by the resource, the following equation is further introduced.

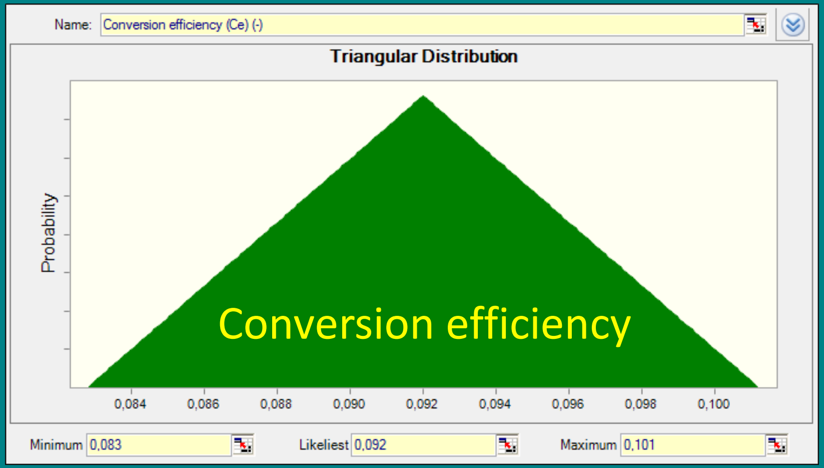
$$P = \frac{(Q_t \cdot R_f \cdot C_e)}{P_f \cdot t} \qquad \textit{Equation (7)}$$

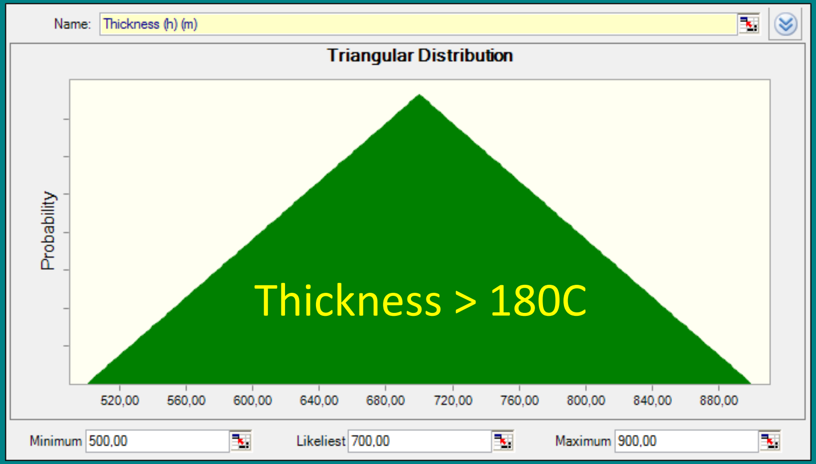
, *where:*

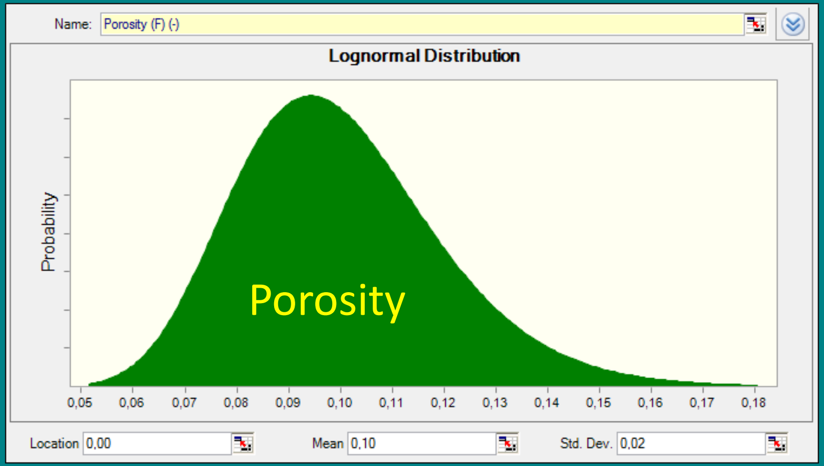
P = power potential, MWe
R_f= recovery factor
C_e = conversion efficiency
P_f= plant factor
t = time in years (economic life)

Patuha volumetric input parameters









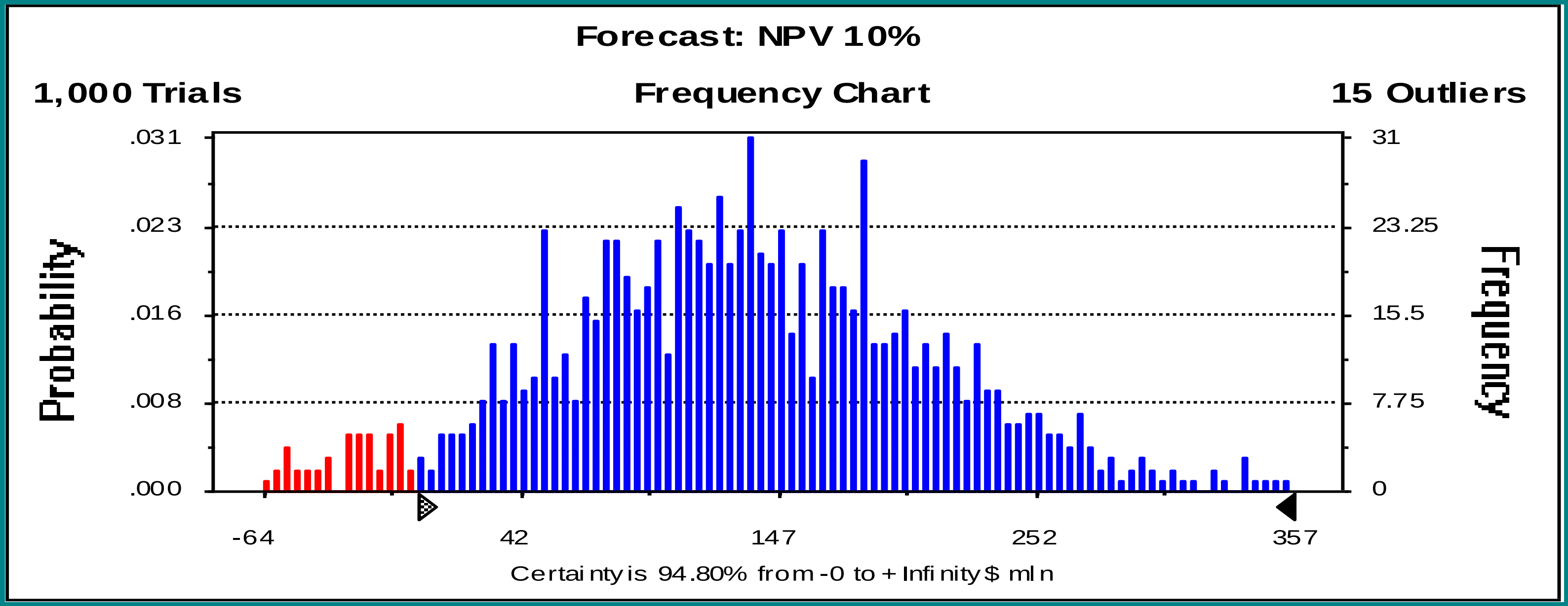
Other stochastic variables:

- Rock density
- Rock specific heat
- Temperature
- Fluid specific heat
- Load factor of plant (Pf)

Patuha commercial risks

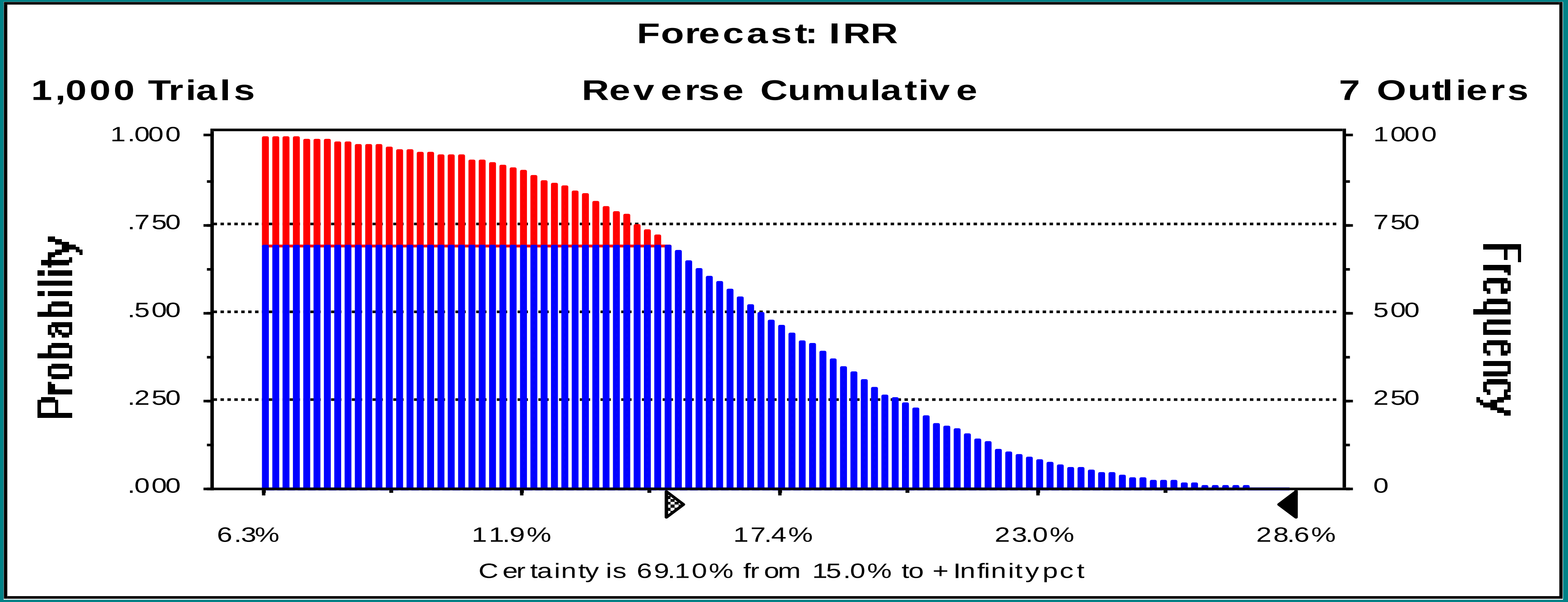
- Volumetric model to be combined with production model and cashflow model
- Combined models to be processed using MonteCarlo sampling
- Output is then histograms for all computed KPIs
  - E.g. NPV, IRR, ME, Pay-out time, Govt Take, $/MWh, etc.
- These histograms can be analysed in terms of risk = probability of *not* meeting a hurdle rate (x value of KPI)
- Using knowledge, mitigation options can be generated and computed for their KPIs (e.g. VoF)
- Alternatively, new information can be acquired (VoI)

Probabilistic processing – KPI#1 (NPV)



- **The NPV distribution shows that there is a 5.2% probability that the 10% NPV will be negative under the assumptions used; on the other hand NPV's in excess of $300 mln cannot be excluded.**

Probabilistic processing – KPI#2 (IRR)

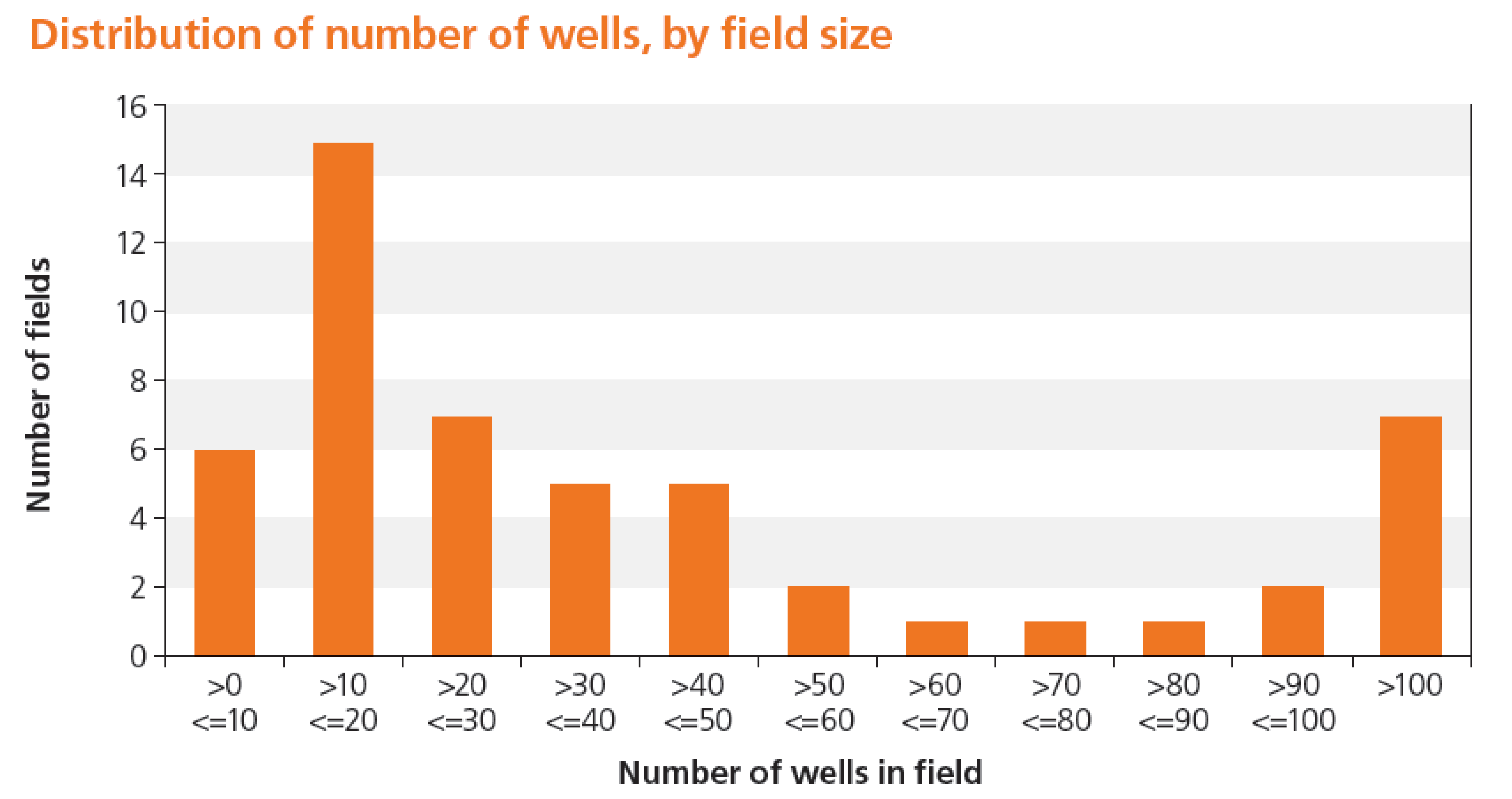


- **The expectation curve for IRR indicates a range between 6% and 29%. There is a 31% probability that the IRR will be less than 15%, an important message for companies with this IRR yardstick.**

Some remarks on drilling risk

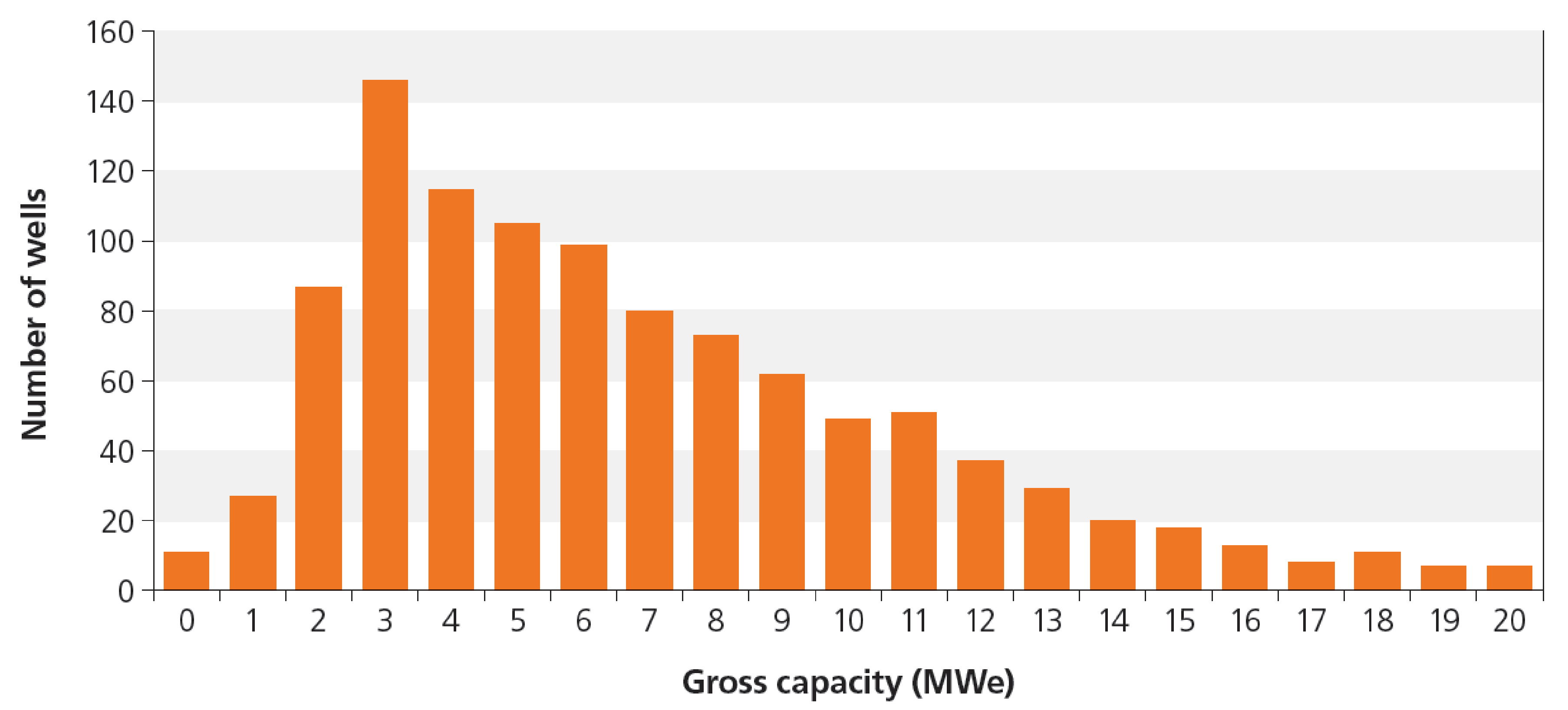
- Risk = probability x undesired outcome
- Drilling risk = e.g. 50% x \$7M = loss of \$3.5M
  - Note: drilling always gives information that may be used successfully subsequently. Therefore, the VoI should be subtracted from the risk.
- GT 'dry hole' is a rarity. 'Failure' normally defined as well capacity < some threshold (typically 3MWe or higher).
- Drilling costs comprise some 35–40% of total capex of a GT project, most of which will be incurred in determining the size, location, and power capacity of the GT resource. This investment will, of course, be lost if no 'reserves'.

GT fields & well count



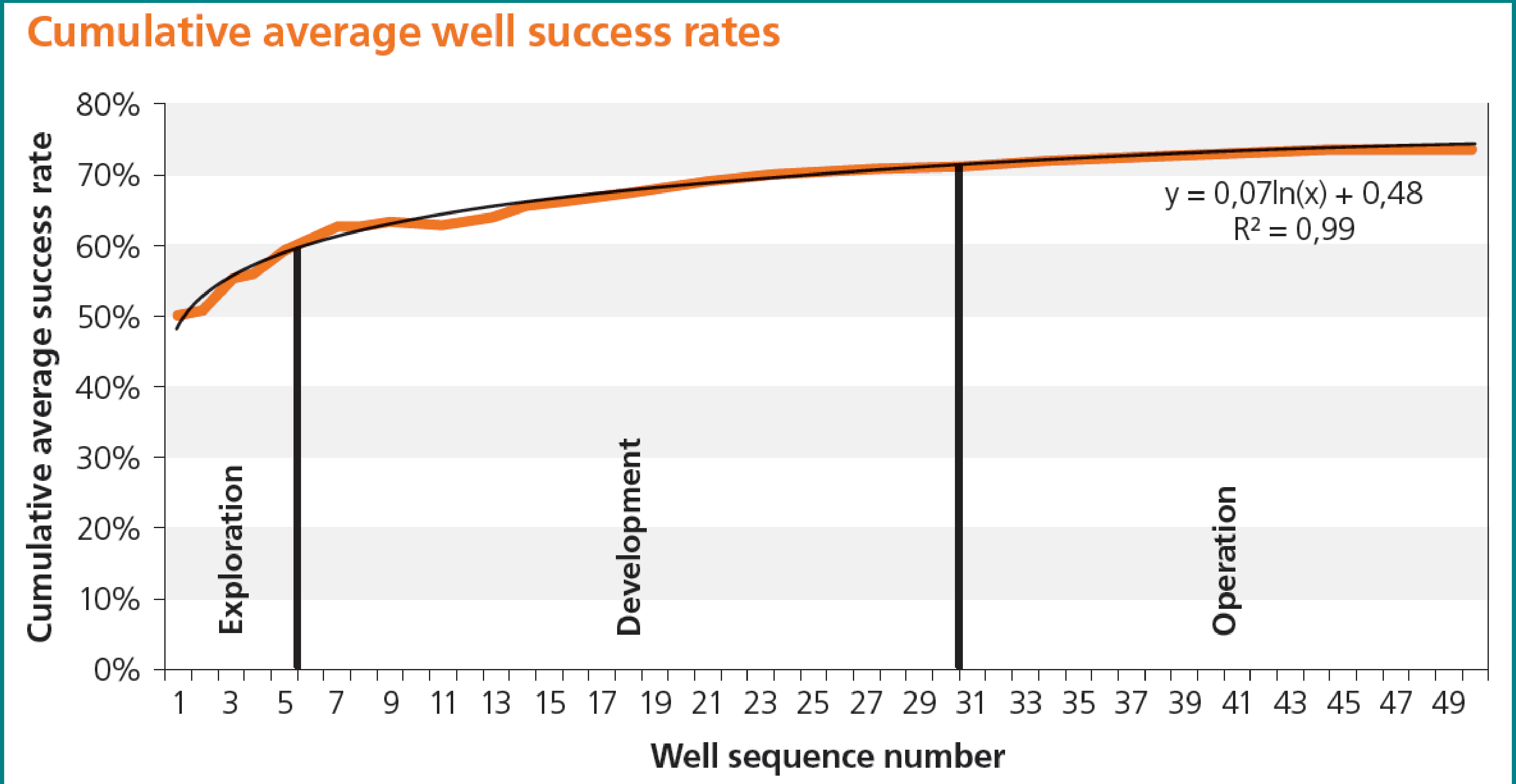
- Ref: *Success of Geothermal Wells: A global study*; International Finance Corporation (WB), June 2014

Distribution of well capacities



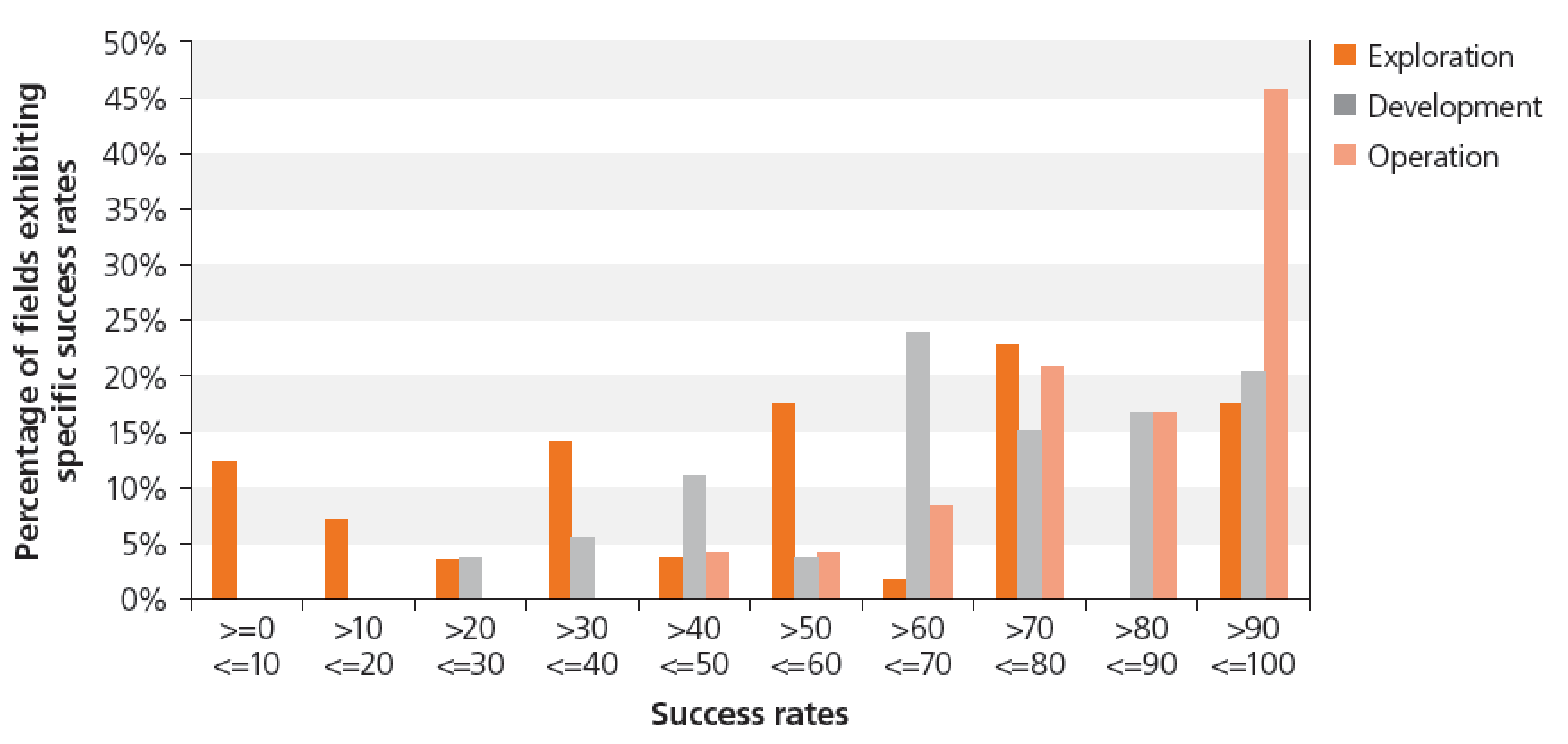
- Incremental individual well capacity subject to large uncertainty

Learning curve – well success rates



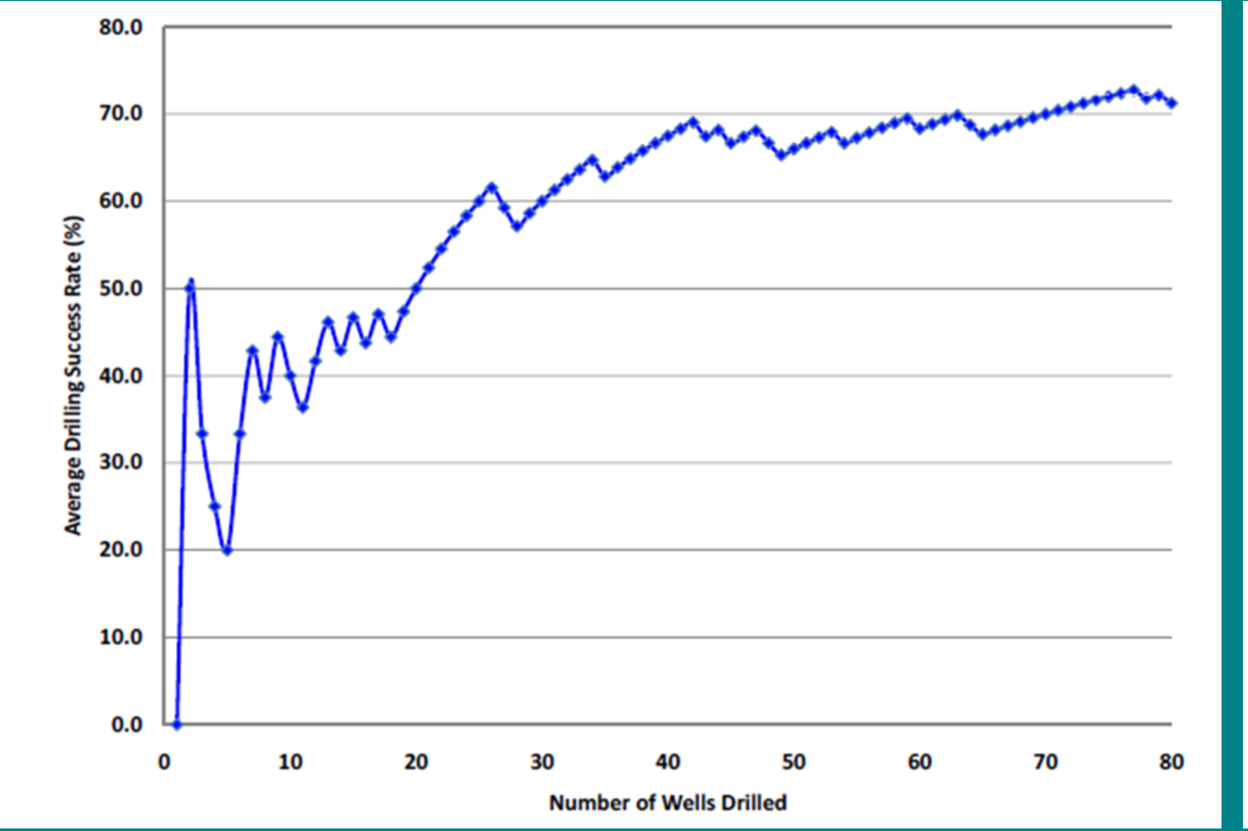
- *Average* success rate!
- Individual fields may deviate.
- See next slide.

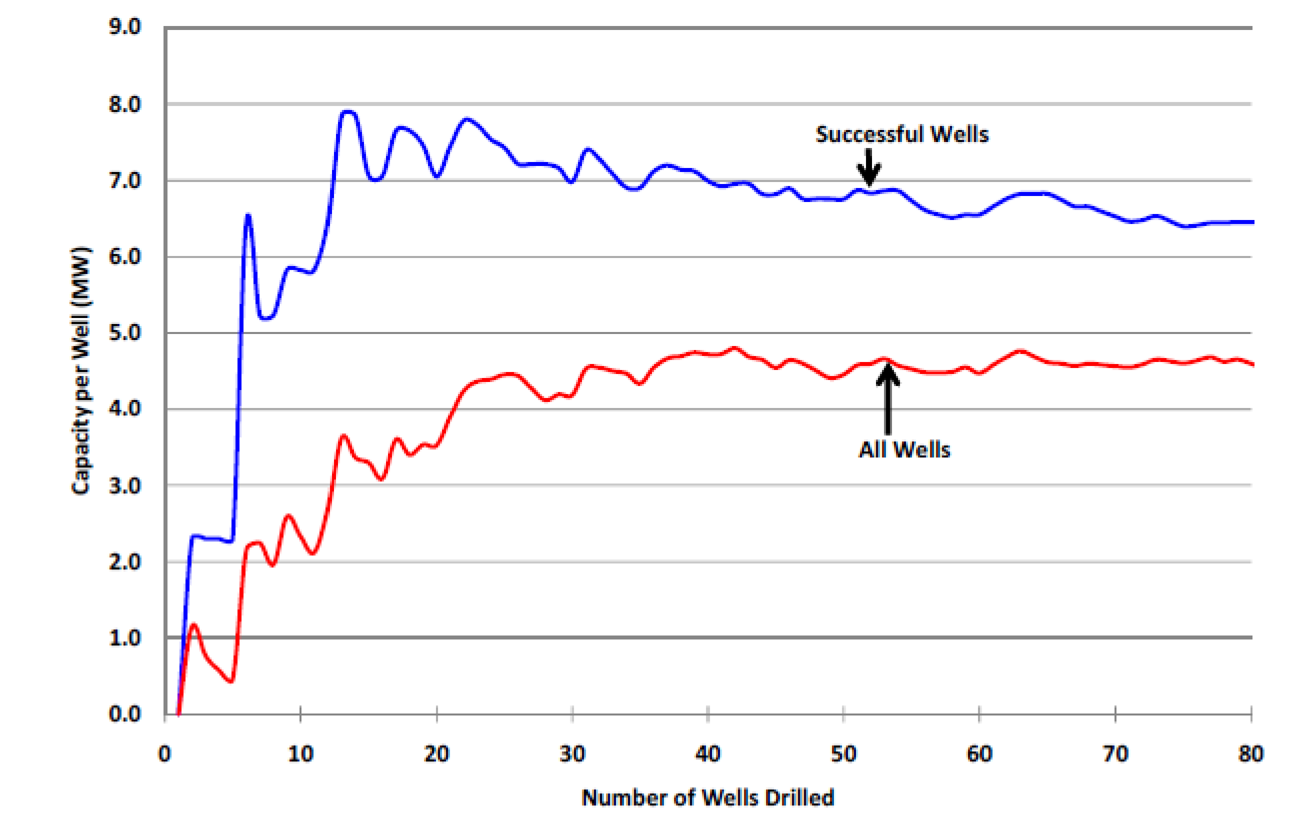
Variation in success rate per phase



- Significant standard deviation per individual field
- This implies a large investment risk
- Not many companies would accept this for the expected RoI
- Govt may assume this risk

Kamojang field (Indonesia)





- Learning effect
- Running average MWe/well

Commercial risks of New GT Law

- **PLN is the monopolist / single buyer (negotiated feed-in tariff)**
  - **Sales price is regulated, CO2-price collapse does not help. Sales price may not honour Δ GT-risk.**
  - **Tariff applies as from COD (Commercial Operation Data)**
- **No cost recovery, hence long pay-out times**
  - **Few companies can afford this!**
- **Due to geography, export not possible**
- **Exploration costs, unclear to what extent it is sole-risk**

- **Challenges of current situation:**
  - **Lack of human resources / experience**
  - **Tendering process to be improved**
  - **Pricing, funding incentives to be clarified**
  - **Access to site / infrastructure + environmental constraints ("Forest areas")**
  - **Fiscal policies**
  - **High risk, high capex per project; but low variable opex! (PV problem)**
  - **Capex req'd to meet 5 GW target: $ 20 billion (Capex $4-6M/MW = 3x fossil fuel)**
  - **Competition from coal; risks of renewable energy >> conventional energy**
  - **Banks do not understand GT**
  - **Lack of incentives for GT investments**

Governments must understand commercial company risk

- Risk assessment is subjective
  - But fundamental is: GT risk >> conventional PP risk.
- Companies have their own perception of (commercial) risk
- **There is a fundamental relationship between (perceived) commercial risk and required return on investment**
  - The higher the risk, the higher the required RoI
- Many companies express this as “IRR hurdle rate”:
  - High risk project may have an IRR hurdle rate of > 15-20%
    - I.e. well above their WACC!
  - But Profit/Investment ratio also common: NPV/PV(Capex)

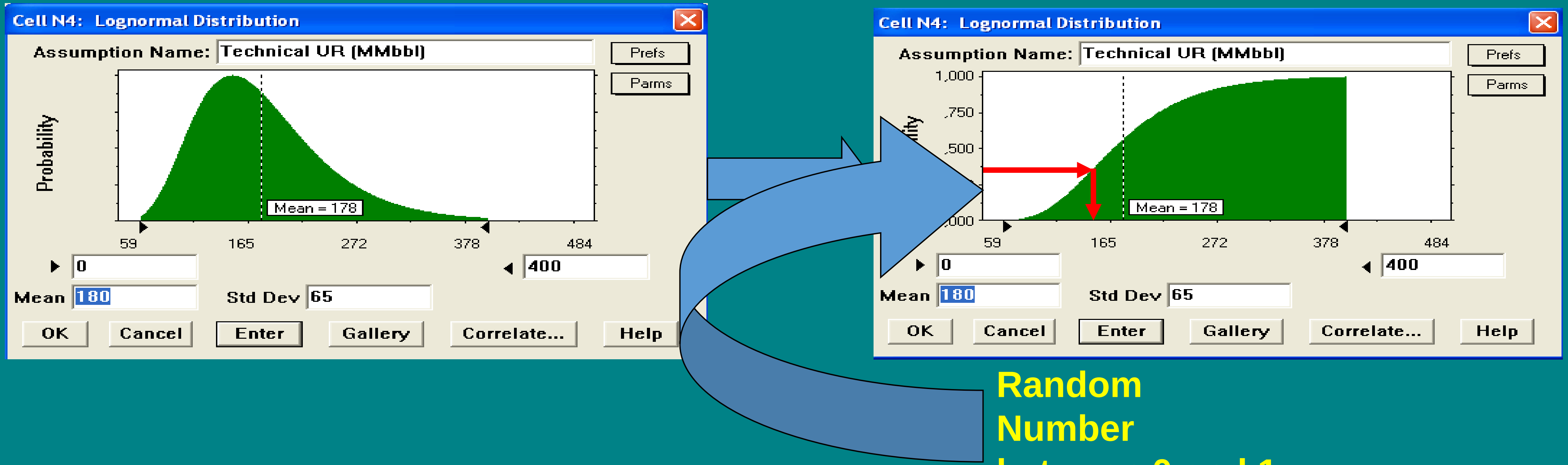
Basic Statistics

- Understanding how to model uncertainties
  - Discrete vs. continuous uncertainties
- 'Frequentists' vs. 'Bayesians'
  - *Using 'experiments only'* vs. *using 'prior knowledge + experiments'*
- Common statistical methods assumed known
  - Pdf, cdf, discrete vs. continuous probabilities, Gaussian distribution, Binomial of Newton, conditional probabilities, etc.
- Apart from common statistical methods, the most pertinent methods for subsurface, DTA and T2B are:
  - Conditional probabilities (Bayesian updating)
  - Monte Carlo sampling
  - Summing / multiplying statistical distributions

MC – Monte Carlo

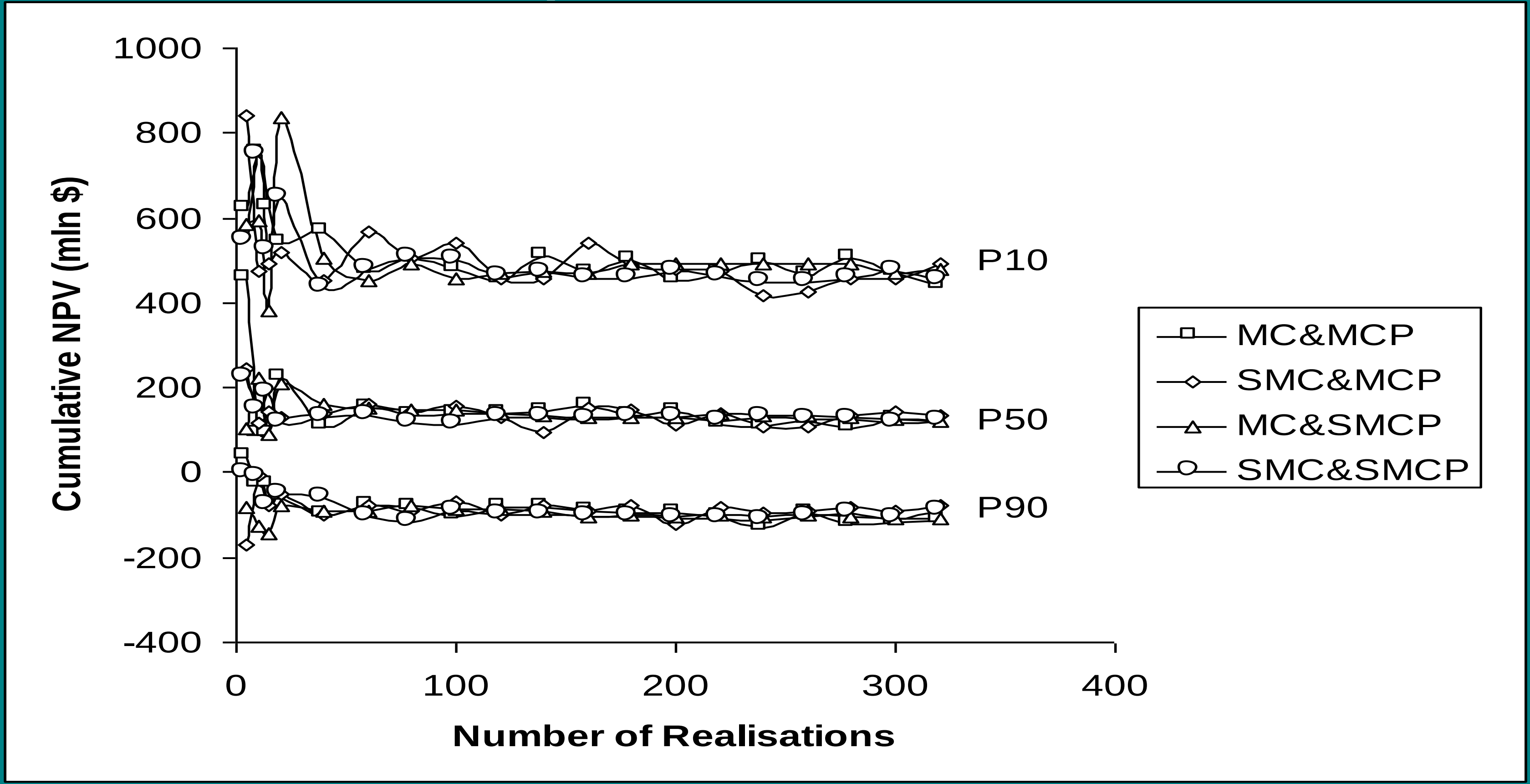
- Probabilistic sampling technique for modelling uncertainties, incl. correlations
- MC uses a RNG that randomly samples a real number between [0;1] from the y-axis of the input cdf of an unknown variable
- Through the cdf, the associated x-value is looked up.
  - This x-value is then used for a 'MC-simulation'
- This is repeated for all stochastic variables: 1 model run
- This is repeated for *n* MC-simulations
- Result: histogram of model-KPIs (e.g. Reserves, NPV, IRR....)

Using RNG to sample from pdf



Do this for each stochastic variable
Per set of stochastic variables compute model output realisation = 1 “simulation”
Repeat sampling of all stochastic variables and simulation *n* times
Construct histogram of model output

Estimation of P10 – P50 – P90 values as a function of sample size

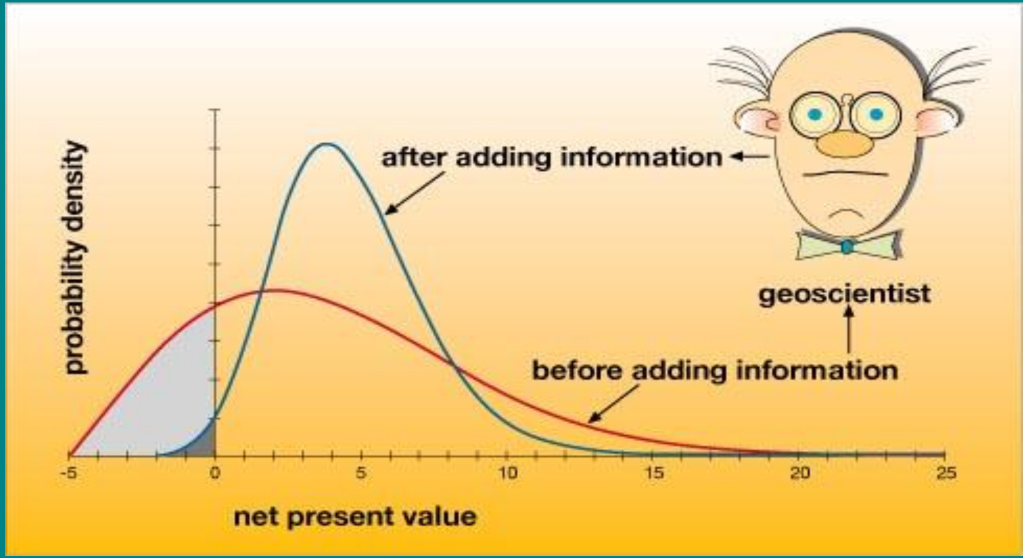


Example - MC, SMC refer to Monte-Carlo or MC-stratified sampling.

MCP, SMCP refer to Monte-Carlo propagation and stratified MC-propagation.

Using "Risk-tolerance" as optimisation constraint

- Project Risk = $\int_{-\infty}^{WACC} IRR * pdf(IRR)\, d(IRR)$
  - **i.e. cum. prob. x average IRR, if it is <WACC**
- Project Risk = $\int_{-\infty}^{0} NPV * pdf(NPV)\, d(NPV)$
  - **i.e. cum. prob. x average NPV, if it is <0**



- The decision-maker should then specify his/her risk-tolerance: for the project in question, and given other (portfolio) considerations, which cumprob x average NPV, i.e. if it is <0, am I prepared to accept?
  - **Risk-tolerance criterion can then be used as optimisation constraint to cut out bad decision-alternatives**

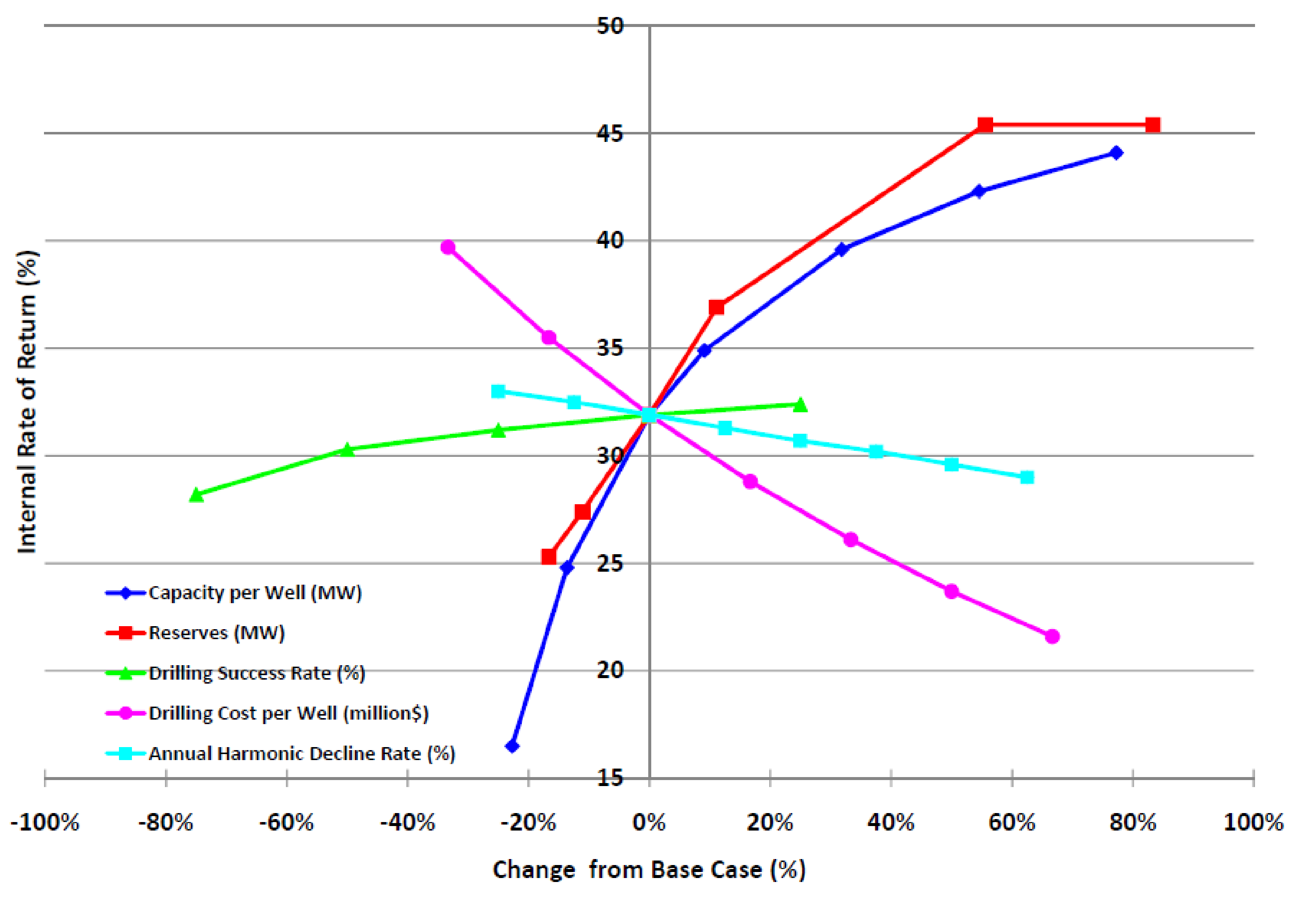
SA – Sensitivity Analysis

- Understanding main high-impact uncertainties + what to do about it: i.e. *create mitigation options*, and *chasing the upside options*
- Should always be part of decision analysis
- Permutation of (series of) uncertain input parameter(s) to study impact on end-result (e.g. economic indicator, decision criterion)
- Derivative analysis
- Normally, this analysis is limited to a single-point, linearised partial derivative
- Examples: tornado chart, spider chart

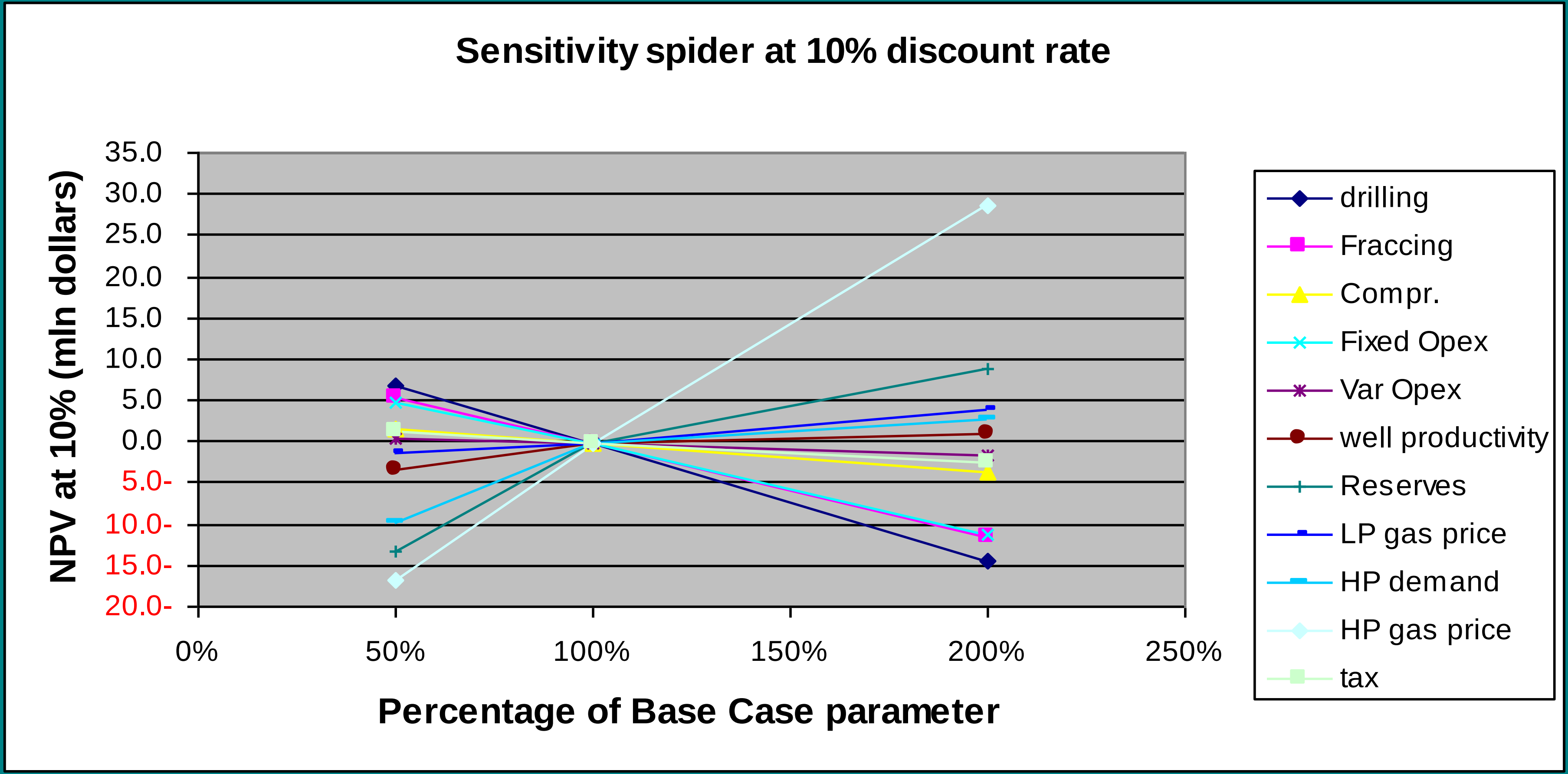
- More sophisticated methods exist
  - **Sampling**
  - **Multi-variate SA**
  - **Mapping of Jacobean**

Sensitivity analysis (deterministic, base case)

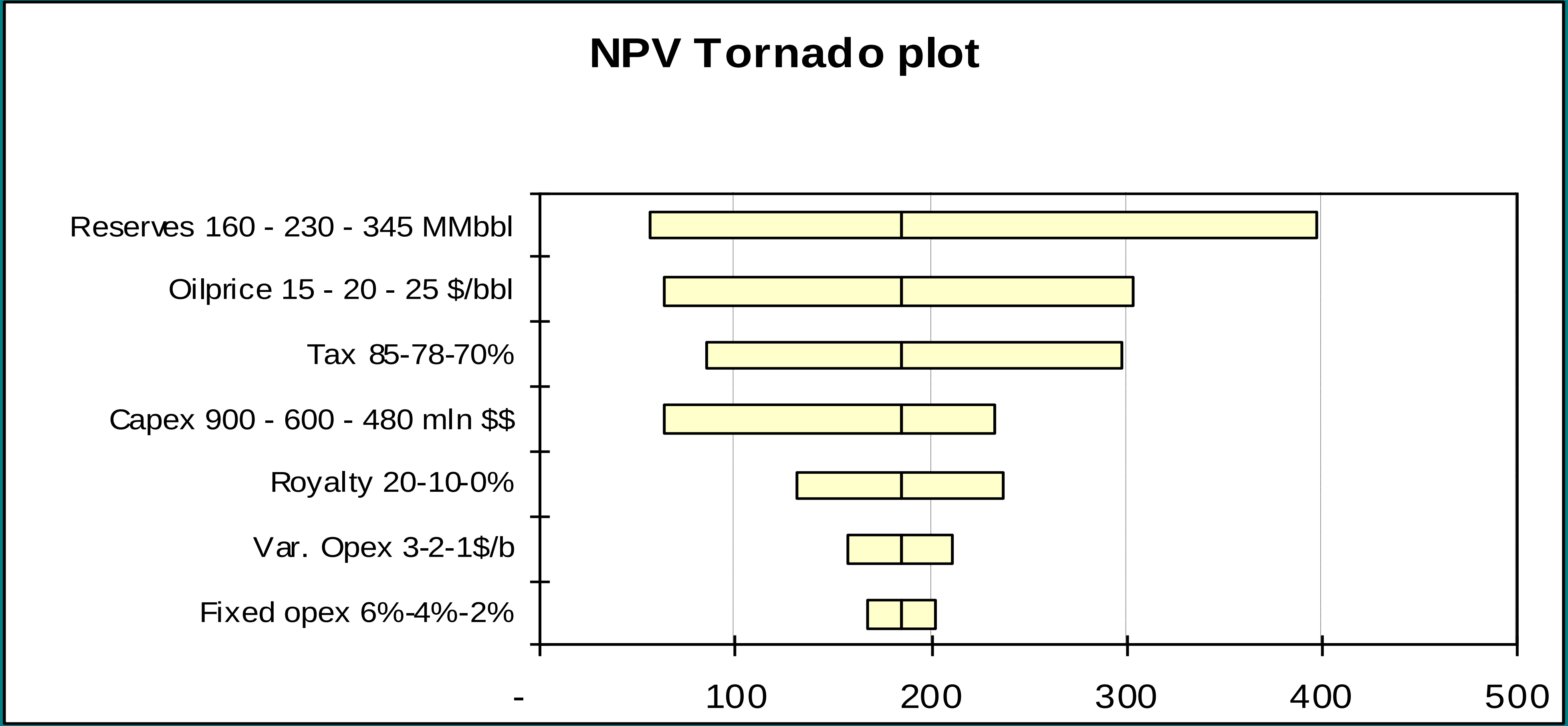
- Reference is “base case” or “most likely case”
- Vary input parameters one by one by a certain relative amount
- Study impact on Key performance indicators of project
- Use this to understand risks of project and to design risk mitigating measures
- Partial derivatives @ base case, multi-variate SA may be more meaningful.



Spider chart (deterministic SA, base case)

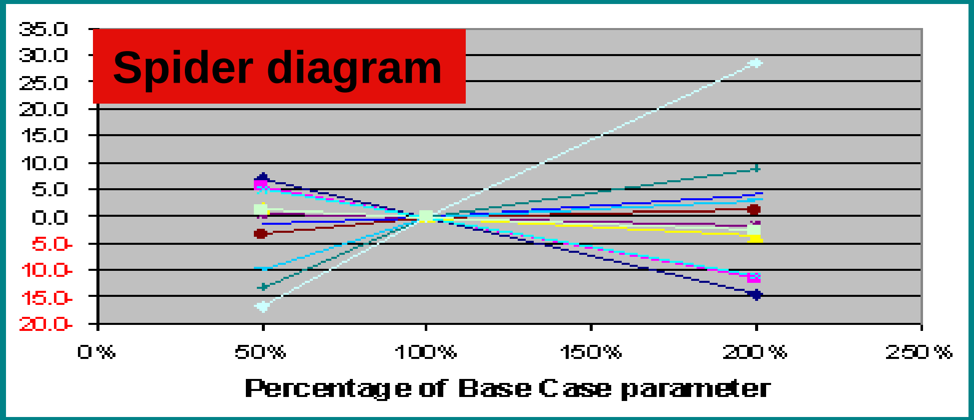


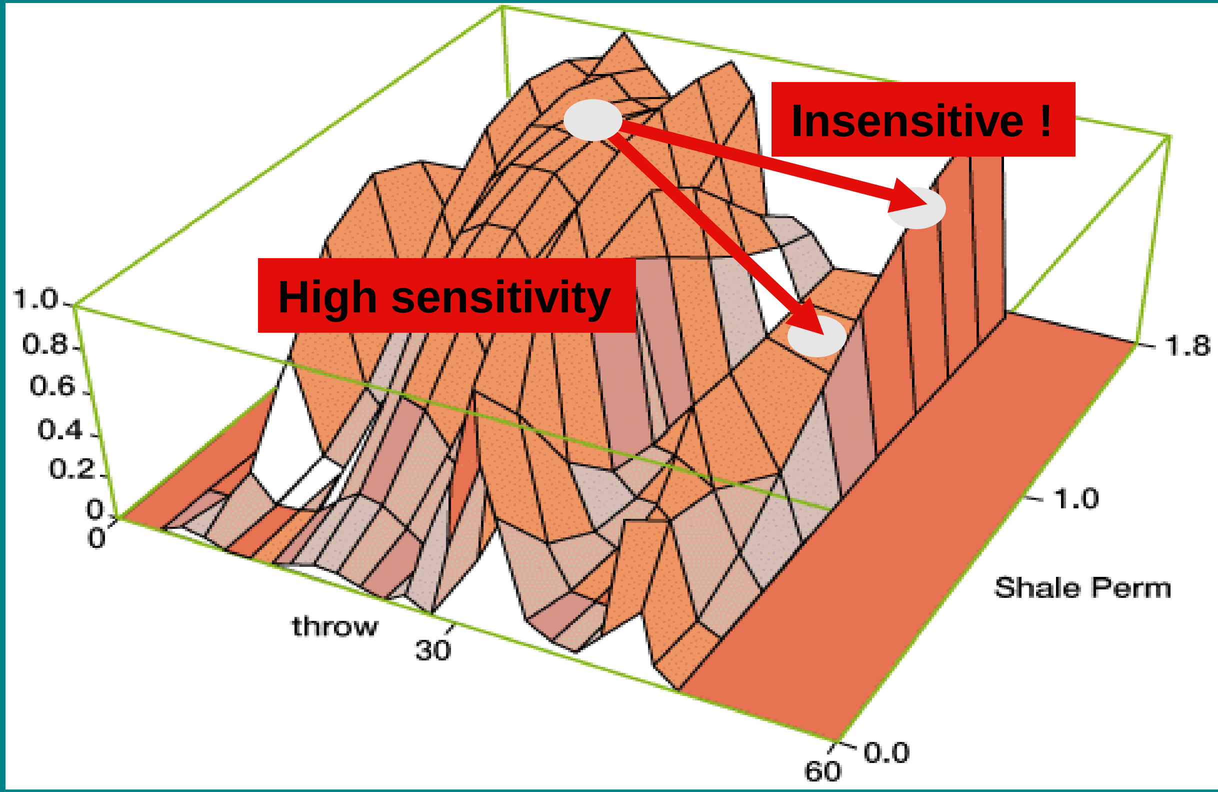
Tornado chart (1) – deterministic SA



Sensitivity analysis

- Beware of complex response surfaces (normal!)
- Standard method: tornado, spider, BUT
- What does a single-point, linearised partial derivative mean on a complex surface?

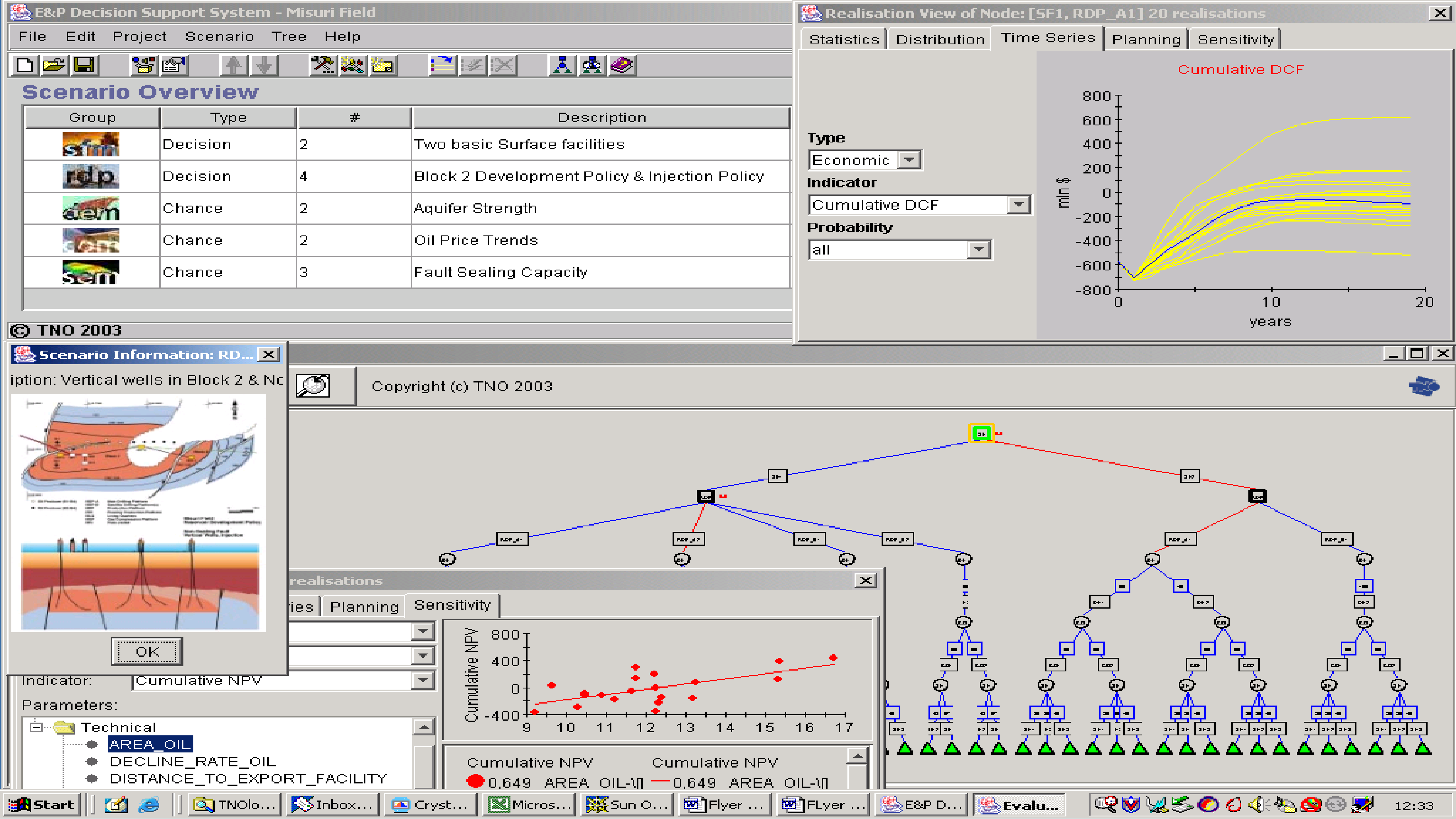




Sensitivity Analysis - probabilistic

- All Monte Carlo samples used: "multi-variate SA"
- All samples plotted in XY-graph
  - X = Input parameter studied (e.g. porosity)
  - Y = Output parameter studied (e.g. NPV)
- Correlation coefficient and tangent of regression line reported as sensitivity

- For a given output parameter (e.g. NPV), this can be done for various input parameters.
  - Parameters can be ranked according to sensitivity
    - Probabilistic Tornado chart: either positive or negative correlation
    - No plus or minus around a base case (there is no base case!)
  - Ranking can be done in various ways, e.g.:
    - Contribution to variance (the relative percentage of variance in a forecast attributable to each uncertain input variable)


E&P Decision Support System - Misuri Field
File Edit Project Scenario Tree Help
Scenario Overview
Group Type # Description
Decision 2 Two basic Surface facilities
Decision 4 Block 2 Development Policy & Injection Policy
Chance 2 Aquifer Strength
Chance 2 Oil Price Trends
Chance 3 Fault Sealing Capacity
© TNO 2003
Realisation View of Node: [SF1, RDP_A1] 20 realisations
Statistics Distribution Time Series Planning Sensitivity
Type
Economic
Indicator
Cumulative DCF
Probability
all
Cumulative DCF
mln $
years
Scenario Information: RD...
iption: Vertical wells in Block 2 & Nc
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realisations
ies Planning Sensitivity
Indicator: Cumulative NPV
Parameters:
Technical
AREA_OIL
DECLINE_RATE_OIL
DISTANCE_TO_EXPORT_FACILITY
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Start TNOlo... Inbox... Cryst... Micros... Sun O... Flyer ... FLyer ... E&P D... Evalu... 12:33

Robustness of a decision

- **Definition of robustness / resilience: concept to be used when recommending a decision.**
- **Given a range of (probabilistic) forecasts of the performance of your asset, “robustness” means to have *adequate flexibility options* during the asset’s life time such that the asset can be steered mid-course to**
  - **1) continue to satisfy a given set of KPI-constraints within certain probability limits (*downside mgt*),**
  - **2) to further optimize the selected optimization-KPI (*upside management*).**
- **Example: given your framing and probabilistic forecast of NPV and IRR within this frame, to design those flexibility options that, when striking them at the appropriate timing, e.g. per “undesired” Monte Carlo time-series realization, will bring back the ex-ante NPV and IRR distributions (pdf’s) to within a predefined range. So, we have to think in terms of dynamic options, and creating these options out of the uncertainty of the predicted range of the asset’s performance.**
- **A set of undesired MC realizations is to be shown + how timely striking built-in flexibility options can steer de NPV and IRR pdf’s back to within some pre-defined constraints.**

CAPM & WACC

- Capital Asset Pricing Model & Weighted Average Cost of Capital: how to use this in DCF?

- Discounting in DCF done to 1) take into account the time-value of money; 2) to include the *uncertainty* in *future* cash-flows (i.e. to incorporate risk)
  - Projected $\$1\ Revenue_{Y=n} < \$1\ Revenue_{Y=n+1} < \$1\ Revenue_{Y=n+2}$ etc.

- For this risk, a premium is added to the discount rate, depending on how good the collateral is: loans vs equity

- See XL CAPM example

DCF – Discounted Cash Flow analysis

- Method to obtain equivalency of cash-flows in different *future* years
- Takes into account *time value of money* (risk-free rate) and *risk* of not being able to pay back capital providers
- Both are derived from CAPM, resulting in a Company's WACC
- Typically, the WACC is used as a Company's discount rate
- Understanding underlying assumptions of DCF analysis: go/no-go decision is usually quite sensitive to the discount rate
- Cash-flows consist of capex, opex, govt take and income
- Govt take usually consists of (mainly) tax and must be modelled *

Government Take: to be modelled in net-after-tax DCF

- Government Take: Tax + Royalty + Other
  - *Tax* = Corporate tax = 25% of yearly *Taxable income*
  - *Royalty* = 2.5% (to be confirmed)
  - Other: e.g. signature bonus, duties, levies, land tax etc.

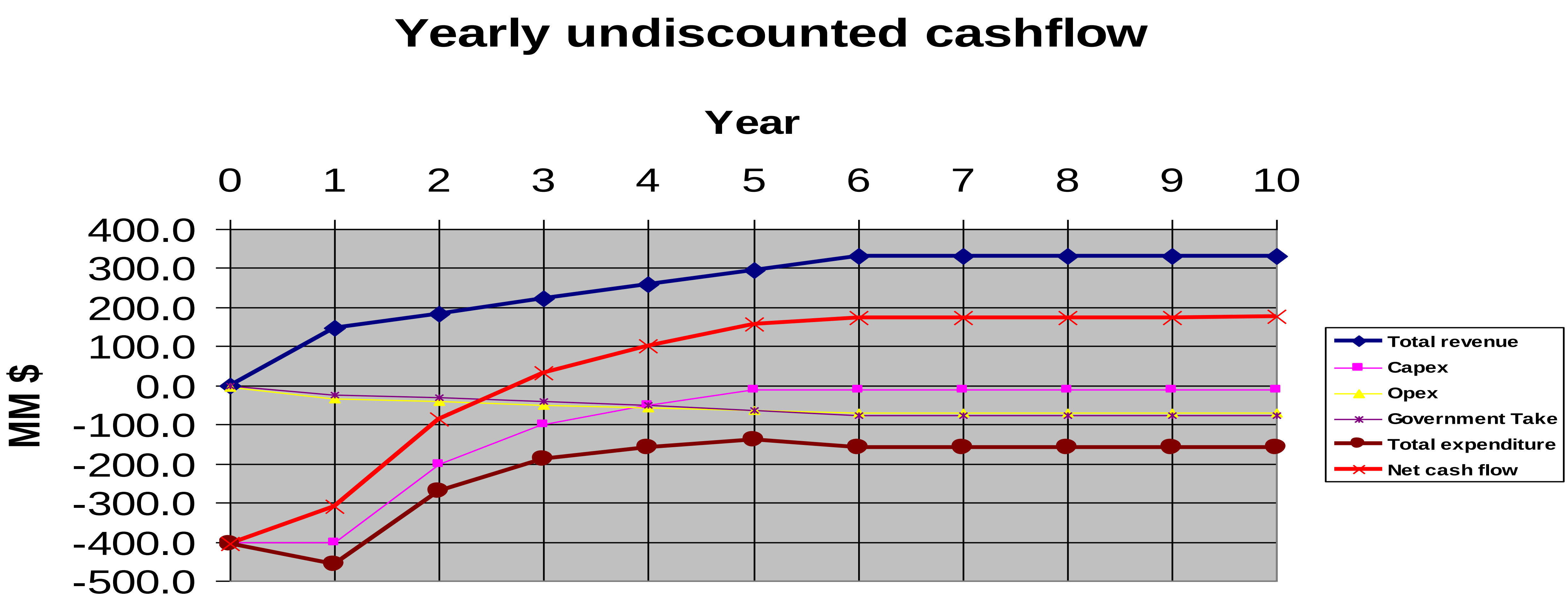
- *Taxable income* is determined by *capex depreciation*:
  - Operator can choose between DB or DDB methods (see XL)
  - Tax credit (GT only): 5%/yr over 6 yrs *add'l depreciation*
  - $\textit{Tax payable}_t = \textit{Taxable income}_t \times 25\% = [\textit{Gross Revenue}_t - \textit{Royalty}_t - \textit{Depreciation}_t - \textit{Opex}_t] \times 25\%$

Discounting, why?

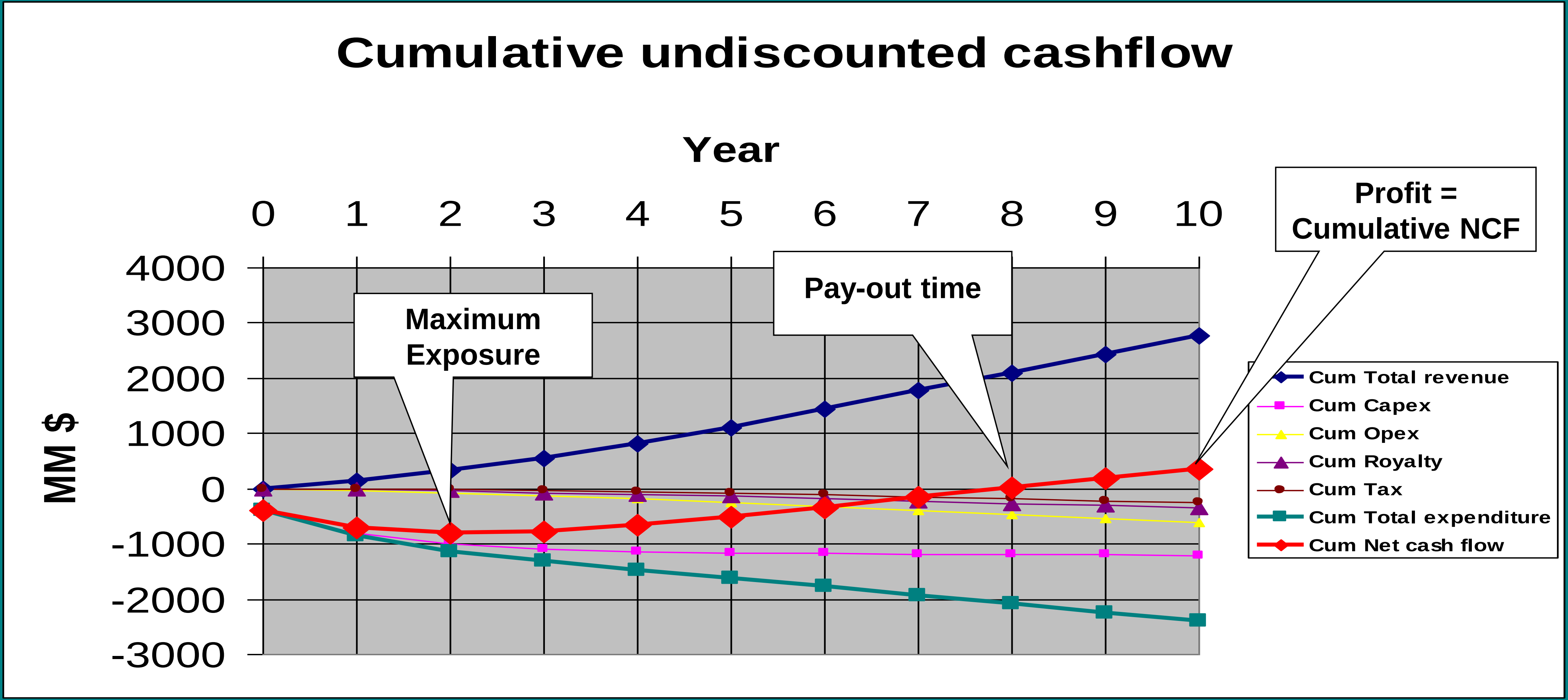
Economists apply a discount factor smaller than 1 to deferred receipts or payments. Analogous to the perspective concept in drawing and painting: objects further away look smaller and less significant.

- Internal financing (loan to project): interest that company would have received from a bank deposit (time value of money).
  - **Most companies not self-financing**
  - **Shareholders expect dividend**
  - **Some companies discount for the opportunity cost of capital**
- External Loan: Time value of money: money today is worth more than money tomorrow. Reasons:
  - **interest (would have been accrued): risk-free interest rate**
  - **risk (something might happen!): risk mark-up on interest rate, depending on "credit rating" of debtor**
- Equity financing: Cost of capital equity
  - **Ref. CAPM, this includes *systemic* risk**

Cashflow, yearly



Cashflow, cumulative



Discount rates affect project economics

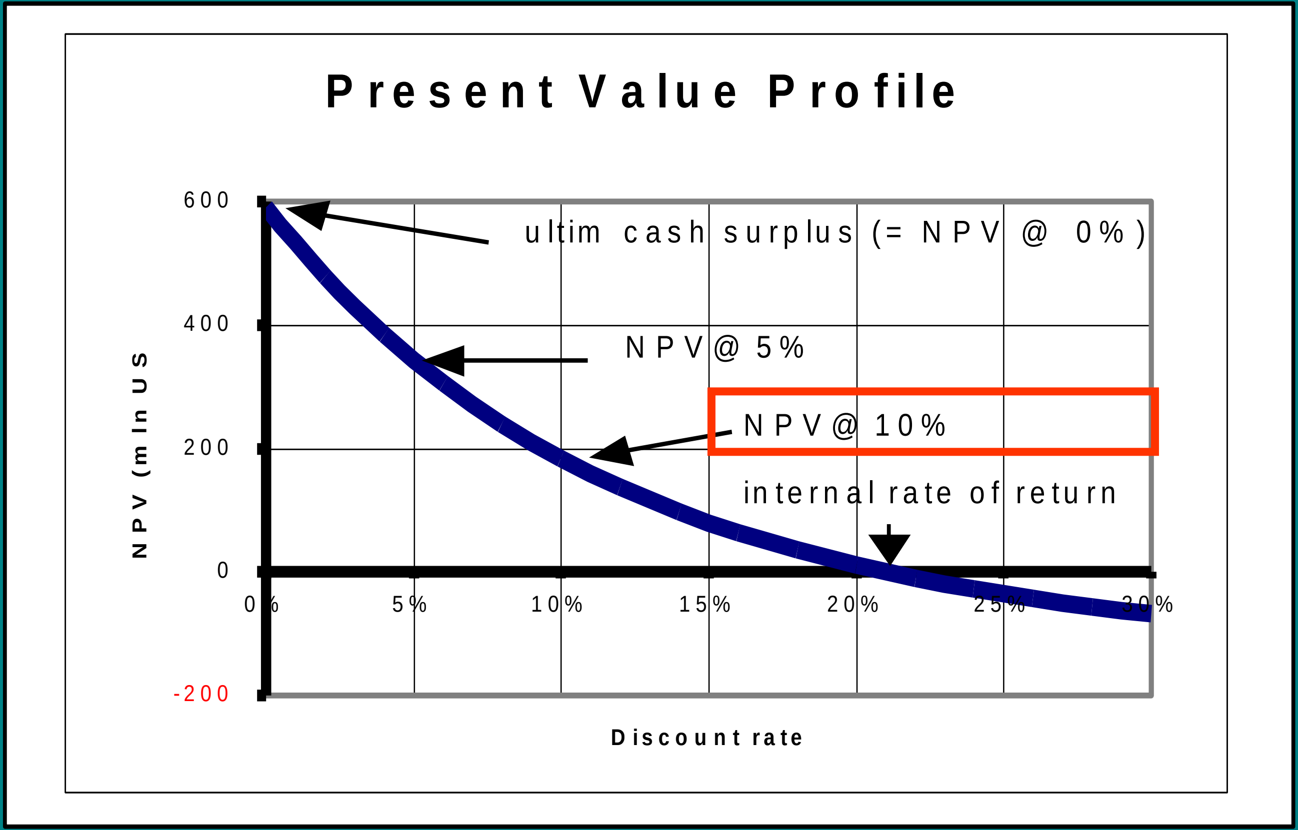
- NPV decreases exponentially with increasing discount rate

- By definition, NPV=0 at DiscRate=IRR
  - or: IRR = dr @ which NPV=0

- NPV<0 if DiscRate>IRR

What is difference discount rate vs. discount factor?

$$NPV(Cashflow) = \sum_{i=0}^{i=n} Cashflow(i)/(1+discount\ rate)^i$$



DCF-KPIs: Key Performance indicators

- The main DCF-KPIs are:
  - ME = Maximum Exposure
  - PoT = Pay-out Time =
  - NPV = Net Present Value = net cumulative discounted cash surplus
  - IRR = Internal Rate of Return = the discount rate req'd to obtain NPV=0
- Derived DCF-KPIs are:
  - P/I = Profit-Investment ratio = NPV / discounted capex
  - UTC = Unit Technical Cost = [capex + opex] / unit of production (e.g. MWh-e)
  - GT = Govt Take = Tax + Royalties + Signature bonus + Duties etc.
  - Risk (in case of multiple scenarios and/or MC (probabilistic analysis)
- DCF-KPIs are important decision criteria for maturing a project to the next Decision Gate.
  - But there are other criteria!

VoI – Value of Information

- Understanding when to propose new data acquisition
- Given a decision framework (decision tree), the Value of new Information can be computed
  - See example Slide (est. value of exploration license)
- New data acquisition costs money, and delays project (time to first production / COD)
- Hence, there should be a method how to quantify the VoI
- Information only has a value, if it has the potential to change your course of action (e.g. improved scoping, design). That potential must be made explicit.

VoF - Value of Flexibility

- All outcomes are uncertain.
- Only gradually will the truth be revealed, i.e. after having committed capital.
  - New wells, new data, production facility capex etc.
- If this info would have been known beforehand, the design might have been adapted.
- One may anticipate on this new info being revealed in time and incorporate that in the design of the facilities / wells.
- A method is required to know when to propose flexibility-options in an engineering design: VoF (as part of DTA).

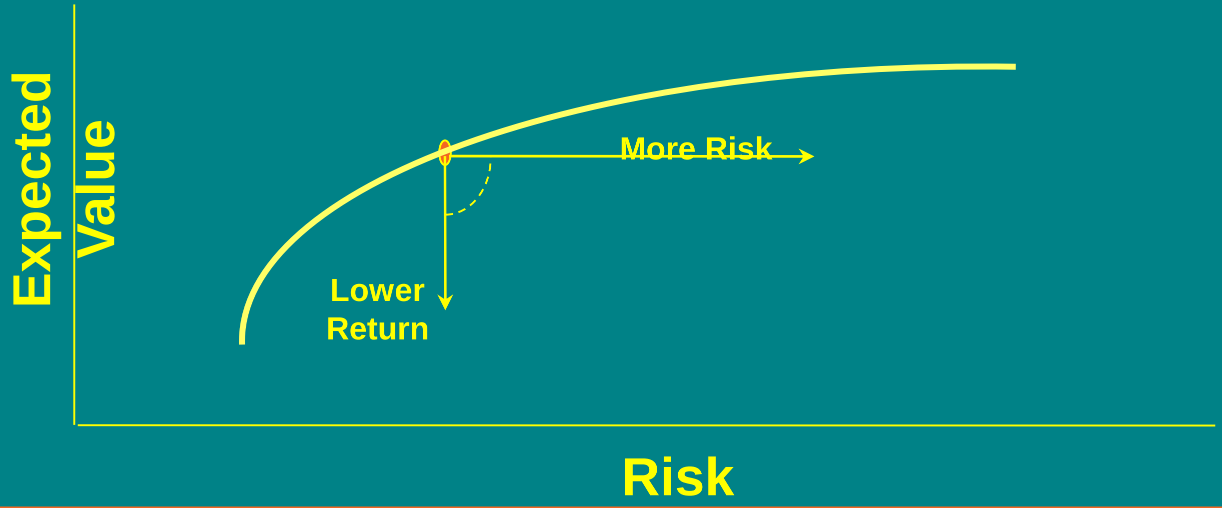
MPT – Modern Portfolio Theory

- Better understanding the nature of risk and how the portfolio of projects determines how to assess individual project risk.
- Projects influence each other:
  - Summing the statistical outcome distributions of different projects influences the statistics of the population of projects

  - *(take example of summing flowrate distributions of different wells)*

"Efficient Frontier"

- In Reward vs. Risk graph, the Efficient Frontier is the locus of all possible combinations of projects for which, at the constraints used:
  - **No lower risk can be obtained without loss of value**
  - **No greater value can be obtained without increased risk**



MSA – Multi-Stakeholder Analysis

- Understanding how to make a MS-project fly
  - If one limits “stakeholder” to (co-)investors in one or more parts of the value chain,
- Different stakeholders may have different:
  - Different objective functions when making decisions
  - Perceptions of Risk, hence different IRR hurdle rate
  - Capitalization, hence WACC discount rate
  - Different portfolio effects of the project being considered
  - Different ways of obtaining security, e.g. concluding contracts with other stakeholders in the value chain
- In joint projects or in value chains, all stakeholders need to have an acceptable risk/reward ratio, i.e. a ‘business case”.
- MSA: tuning certain variables such that *all* stakeholders obtain a business case, taking into account their different perspectives

DQ - Decision Quality

- A way to measure and monitor the quality of the decision-making process
- Q: how would you measure the quality of a decision?
  - By the difference outcome vs. plan?
  - Otherwise?
- Definitions:
  - Decision Quality - the framework that defines the requirements of a good decision
  - Dialogue Decision Process - a collaborative approach to address complex issues to reach quality decisions
  - Decision Analysis - the concepts and tools that produce clarity about the best choice in an uncertain and dynamic environment
- See also ‘Stanford Strategic Decision and Risk Management’

What do decision-makers need to know from the project team?

Our Thoughts about What Managers Need to Make Good Decisions

- They need to know that the team looked a range of different alternatives.
- For each alternative they need to understand
  - The value and its top drivers
  - The risk and its top drivers
  - What combination of outcomes would cause them to change their choice.
- Need to believe that uncertainty range reasonably captures the range of possible outcomes.
- They need to have confidence that their **decision** is robust under a range of possible outcomes.
- They want to know that all projects have been evaluated on consistent basis.

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What is a ‘good’ decision?

My personal suggestions

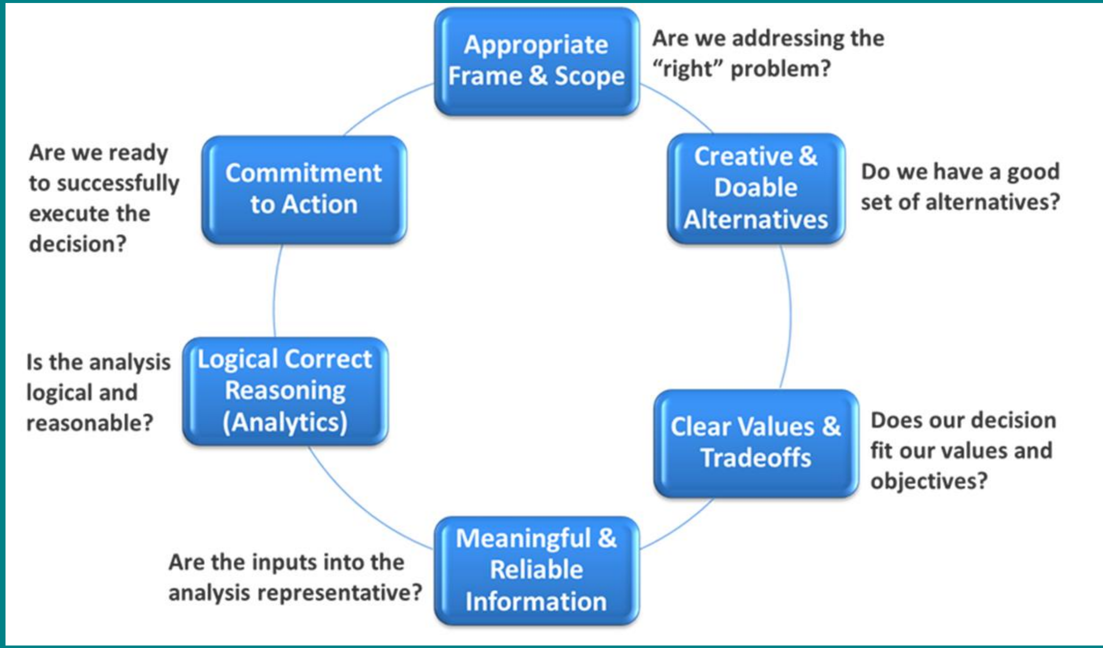
- A good decision is a decision that has been taken according to a *precise* process that is *consistently* applied to different cases
  - **Precise**: unambiguous, repeatable
    - Little room for subjective, haphazard process steps, nor for omitting steps
    - Beware: process should not become a “box-ticking exercise” & should continuously invite critical thinking / innovation so as to improve corporate learning
  - **Consistent**: this allows *corporate learning (*signal-noise ratio*)*

- A good decision is *not* a decision that resulted in a good (or acceptable) outcome!
  - Certainly not in case of large uncertainties! Being lucky is not same as being good.
  - But when applied consistently, process should lead to **excellent** *average outcome*

- Staff should not be rewarded based on outcome, but on having properly applied the agreed process
  - And on proposing process innovations
    - Staff should not be rewarded for being lucky!

DQ - looking back on the process

- Establishing Decision Quality is the last step in the Decision Analysis process.
- Look-back on the decision *process* to assess whether it had sufficient quality:
    - appropriate frame
    - creative & doable alternatives
    - clear values and tradeoffs
    - meaningful reliable information
    - logically correct reasoning
    - *fostering formal learning and working towards "best practices"*
    - commitment to action
- Note: DQ ≠ decision outcome!



Wrap-up

- Decision Analysis (DA) comprises many methods and processes
- DA is at the core of how a company conducts its business
- DA and DQ are a company’s critical succes factors
- Detailed knowledge and skills can only be acquired over many years, but growing personally in this domain can be very rewarding
- In this short-course, only a flavour was provided
- Consider joining the 5-day course later this year